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RADIONUCLIDES IN SURFACE SOIL AT THE NEVADA TEST SITE

by

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ABSTRACT

In 1981, the U.S. Department of Energy began the Radionuclide Inventory and Distribution Program, an attempt to assess the amount and distribution of radioactivity in surface soil at the Nevada Test Site (NTS). Over the next several years, researchers used a combination of aerial radiological surveys, soil sampling, and *in situ* measurements to study the regions of the NTS where soil radioactivity was above background levels. These regions included the ground zeros of above-ground nuclear tests, underground tests that vented, and some safety shots, as well as the sites of nuclear rocket experiments.

The results of the program were published in a series of five reports between 1983 and 1989. In this report, those results have been combined to provide an integrated picture of the current levels of soil radioactivity on the NTS. The estimated inventories of the nine most important manmade radionuclides have been reviewed (and in some cases recalculated), decay-corrected to January 1, 1990, and tabulated. New distribution maps have been prepared that show isopleths of decay-corrected radionuclide concentrations over the entire NTS. Two additional maps show the measurement locations where the gamma exposure rate exceeds 100 μR/hr and where the ^{239,240}Pu concentration exceeds 500 pCi/g.

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RADIONUCLIDES IN SURFACE SOIL AT THE NEVADA TEST SITE

BACKGROUND

The United States began testing nuclear weapons at the Nevada Test Site (NTS) in January 1951. Since then, the NTS has become the nation's primary site for testing new nuclear weapons and studying the effects of nuclear explosions on structures and military equipment. Other nuclear energy projects at the NTS have studied safety requirements for storing and transporting nuclear weapons, explored peaceful uses of nuclear explosives,and developed nuclear rockets and ramjet engines. In all, more than 600 nuclear explosions have taken place at the NTS as part of these programs.

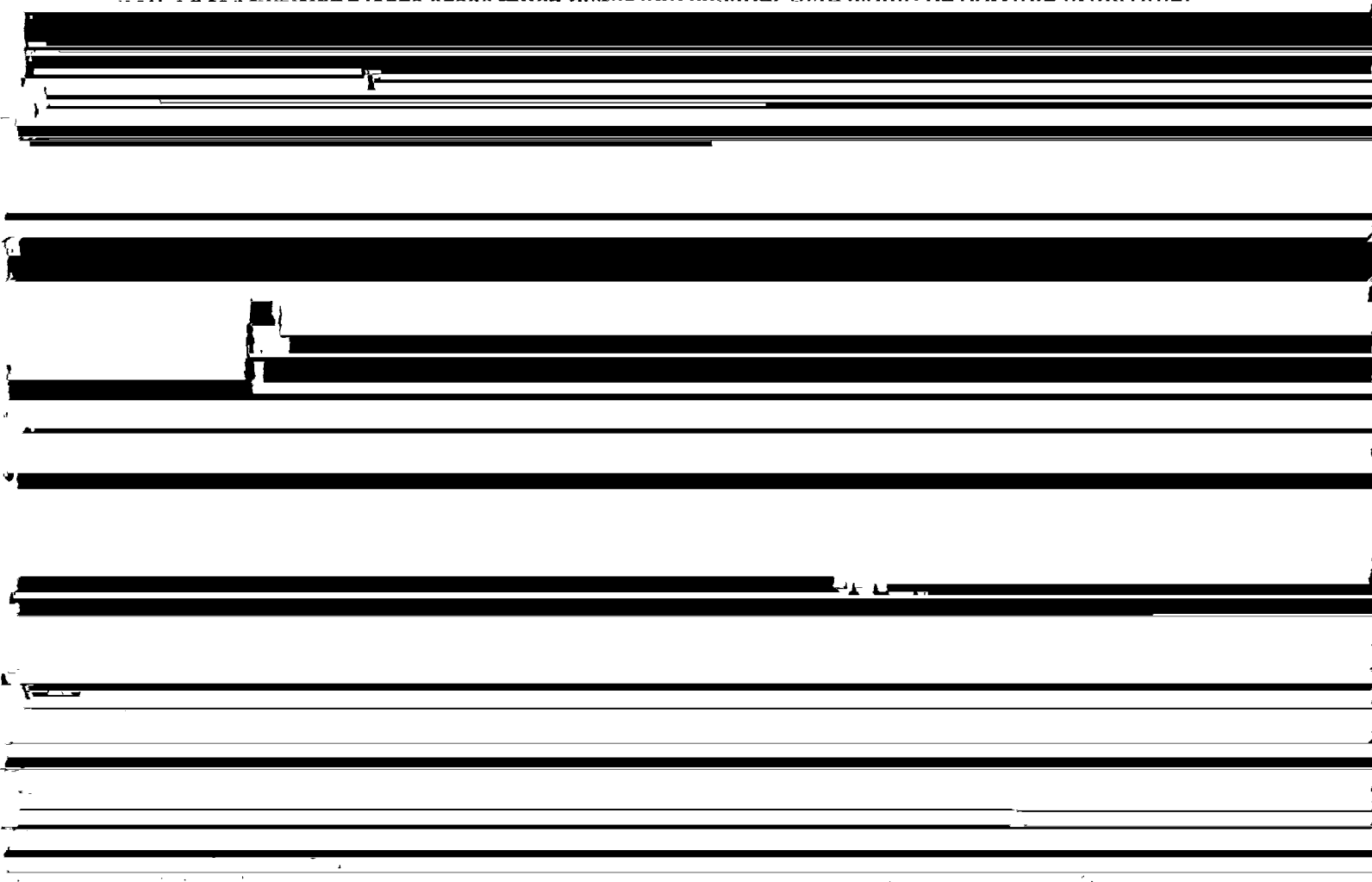
One result of these explosions is that the surface soil in many parts of the NTS contains measurable amounts of several long-lived radionuclides. Almost all of the 100 above-ground tests contaminated the soil near the ground zero (GZ). Several underground tests were cratering experiments that threw radioactive rock and soil hundreds of feet from the GZ, and some deeper underground tests vented radioactive material to the surface. A few safety tests, in which a nuclear device was destroyed by conventional explosives, scattered plutonium (and in some cases uranium) over the nearby ground. Finally, radioactive debris from many tests was deposited as fallout over the northern and eastern parts of the NTS.

Radiation levels at the NTS are monitored regularly, and safety officials have identified and fenced off the areas where the soil is heavily contaminated. In many other areas, radionuclide levels are not high enough to warrant closing the area but are still above background. These areas may pose a long-term risk to people working in them regularly and to people who may visit them in the future if the NTS is ever returned to the public domain. Evaluating this risk requires detailed information on the amounts of various radionuclides in the soil at different locations. Knowledge of the amount and distribution of soil radioactivity will also be important for the eventual cleanup of contaminated areas.

Several studies of radionuclide distribution were done on the NTS in the 1970s, but all were limited in scope. A series of aerial radiological surveys measured gamma-exposure rates over much of the NTS, but they did not measure individual radionuclides. The studies that did measure individual radionuclides usually focused on transuranic elements (americium and plutonium) and were limited to relatively small areas near GZs and safety shot sites. The data for those studies were obtained by collecting and analyzing large numbers of soil samples, a method too expensive and time-consuming to use for large-scale surveys.

In the mid-1970s, scientists from Lawrence Livermore National Laboratory (LLNL) and the U.S. Department of Energy's (DOE) Environmental Measurements Laboratory developed *in situ* spectrometry, a technique for measuring gamma-emitting radionuclides

in surface soil (Beck *et al.*, 1972; Anspaugh, 1976). This method was used for a survey of Frenchman Flat in 1978 and 1979, in a cleanup and treatment experiment in Area 11 in 1981, and in cleanup operations at several off-site areas in the late 1970s. It proved to be a useful method for surveying large areas much faster and cheaper than would be possible using other



methods.

In 1981, the DOE began a project that would use this new technology to carry out a thorough radiological survey of the surface soil on the NTS. This project, the Radionuclide Inventory and Distribution Program (RIDP), took five years of field work and another three years of data analysis to complete. It resulted in estimates of the total amount (inventory) and the distribution of radionuclides in the soil in all parts of the NTS that had been affected by NTS operations.

The methods and results of the RIDP were published in a series of five reports:

Report #	Regions Covered	Reference
1	Galileo (Area 1)	McArthur and Kordas, 1983
2	Areas 2 and 4	McArthur and Kordas, 1985
3	rest of Yucca Flat	McArthur and Mead, 1987
4	Areas 18 and 20	McArthur and Mead, 1988
5	rest of the NTS	McArthur and Mead, 1989

The purpose of this report is to update and summarize those results, with the aim of

measurable amounts in soil at one or more locations on the NTS (Table 1). The methods used in the project do not allow ^{239}Pu and ^{240}Pu to be measured separately; all that can be determined is the total activity of the two isotopes, denoted as $^{239,240}Pu$. The ratio of ^{239}Pu to ^{240}Pu in fallout from nuclear tests conducted at the NTS ranges from about 12 to over 6,600 (Hicks and Barr, 1984).

Finally, radionuclides "of NTS origin" are those resulting from testing on the NTS. All surface soil on the NTS contains manmade radionuclides from global fallout, that is, fallout from high-yield U.S. thermonuclear tests in the Pacific and tests conducted by other countries. (The contribution of the relatively low-yield fission tests conducted at the NTS to global fallout is small.) Regions of the NTS where the levels of radionuclides in the soil were comparable to those due to global fallout were considered areas of background activity; such areas were assumed to have no radionuclides of NTS origin in the surface soil. Levels above those attributable to global fallout were assumed to result from NTS activities.

The general areas affected by NTS activities were known before the RIDP began. The project's resources were focused on these areas, and only a few measurements were made in background areas.

TABLE 1. IMPORTANT MANMADE RADIONUCLIDES IN NTS SURFACE SOIL

Radionuclide	Half-life (y)[1]
^{60}Co	5.26
^{90}Sr	28.1
^{101}Rh	3.1
^{102m}Rh	2.9
^{125}Sb	2.7
^{133}Ba	10.7
^{134}Cs	2.05
^{137}Cs	30.2
^{152}Eu	13.
^{154}Eu	16.
^{155}Eu	1.81
^{174}Lu	3.6
^{238}Pu	86.
^{239}Pu	24,400.
^{240}Pu	6,580.
^{241}Am	458.

[1]Most values are from the *CRC Handbook of Chemistry and Physics*, 65th Edition (1984), CRC Press, Boca Raton, Florida; the value for ^{133}Ba is from the *Table of Isotopes*, 7th Edition (1978), Wiley, New York.

METHODS

The strategy developed to meet the RIDP's objective, as outlined in the project operations plan (Kordas and Anspaugh, 1982), combined the three methods used in earlier studies: aerial surveys, soil sampling, and *in situ* spectrometry. Details of how these methods were used were given in the RIDP reports, especially Report 1. The following description is only a summary.

Aerial Surveys

Between 1976 and 1984, EG&G, Inc., made a new series of aerial radiological surveys of much of the NTS:

Area	Date of Survey	Reference
Areas 25 and 26	September 1976	Tipton, 1979
Yucca Flat	August–September 1978	Fritzsche, 1982
Areas 18 and 20	October–November 1980	Feimster, 1985
Area 11	January 1982	Clark, 1983
Area 5	February 1982	unpublished
Areas 16 and 30	June 1983	Bluitt, 1986
Areas 12, 15, 17, 19	October–November 1984	Jobst, 1986

The surveys were carried out with an array of NaI(Tl) scintillation detectors mounted on a helicopter. Previous aerial surveys had been made from fixed-wing aircraft; the slower speed and greater maneuverability of the helicopter allowed wider coverage and better resolution.

The results of the aerial surveys were used to define the precise areas to be surveyed with the primary measurement technique, *in situ* spectrometry.

In Situ Spectrometry

To help coordinate the field activities, the *in situ* measurements were carried out in a series of surveys of different areas (Table 2). Most of these areas contained at least one GZ or other localized source of contamination. Such areas were usually identified by the name of a test, such as "Galileo," although the chosen name did not necessarily reflect the most important source of contamination in the area. The regions covered in the Area 15, Areas 12 and 19, Areas 17 and 18, Pahute Mesa, and Miscellaneous surveys had no GZs. Soil radioactivity in those areas was generally uniformly distributed at relatively low levels.

The portions of the NTS covered by the *in situ* surveys are shown in Figure 1. They include all the GZs of above-ground nuclear tests, the GZs of underground tests where significant amounts of radioactivity reached the surface, safety-shot sites, the rocket test facilities in Area 25, and other places where aerial surveys showed elevated levels of radioactivity. For the most part, those portions of the NTS not covered by *in situ* surveys were

TABLE 2. SUMMARY OF RIDP SURVEYS

Region	Number of *in situ* measurements	Number of soil profiles	Number of chemical analyses	approximate dates
Galileo	136	11	3	Aug.–Nov. 1981
Kepler	121	9	4	Dec. 1981–Apr. 1982
Whitney	173	17	7	Feb.–Apr. 1982; June 1983
Diablo	53	12	4	May 1982
Baneberry	181	15	3	May–July 1982; June 1983
Sedan, Smoky	257	25	10	Aug.–Sept. 1982
Wilson	207	23	3	Oct.–Nov. 1982
Quay	223	17	7	Dec. 1982–Feb. 1983
Hornet	376	25	12	Feb.–May 1983
Pahute Mesa	25	0	0	June 1983
Schooner	62	11	5	July 1983
Cabriolet	220	13	6	Aug.–Oct. 1983
Johnie Boy	132	14	5	Nov.–Dec. 1983
Little Feller I & II	94	18	8	Jan.–June 1984
Danny Boy	107	11	5	May–June 1984
Areas 25 & 26	181	24	5	Feb.–March 1984
Areas 17 & 18	176	15	6	Aug.–Nov. 1984 & 1985
Area 15	36	4	1	Oct.–Nov. 1984
Pinstripe, GMX	222	22	16	Jan.–Feb., May 1985
Plutonium Valley	172	22	11	Mar.–May 1985
Buggy	76	13	5	June–July 1985
Areas 12 & 19	118	24	13	June–July 1985
Oberon	30	10	5	Nov.–Dec. 1985
Frenchman Lake	291	29	6	Sept. 1985–Jan. 1986
Miscellaneous	81	15	8	Sept. 1985; Feb. 1986
Total	3,750	399	158	

known (from aerial surveys, ground-based monitoring, and the history of NTS operations) to have no contamination from NTS activities. The main exception was the mountain ranges surrounding Yucca Flat, where aerial surveys have shown above-background levels of radioactivity. These mountains were inaccessible to the survey vehicle. In addition, for safety reasons, measurements were not made in craters such as those at Sedan, Schooner, and Cabriolet.

The *in situ* measurements were made with a collimated high-purity germanium detector suspended about 7.4 m above the ground. The detector was mounted on a vehicle capable of off-road travel. Inside the vehicle were the other components of the measurement system, including an amplifier and power supply, a pulse-height analyzer, and a desktop computer. The system was maintained and operated by EG&G.

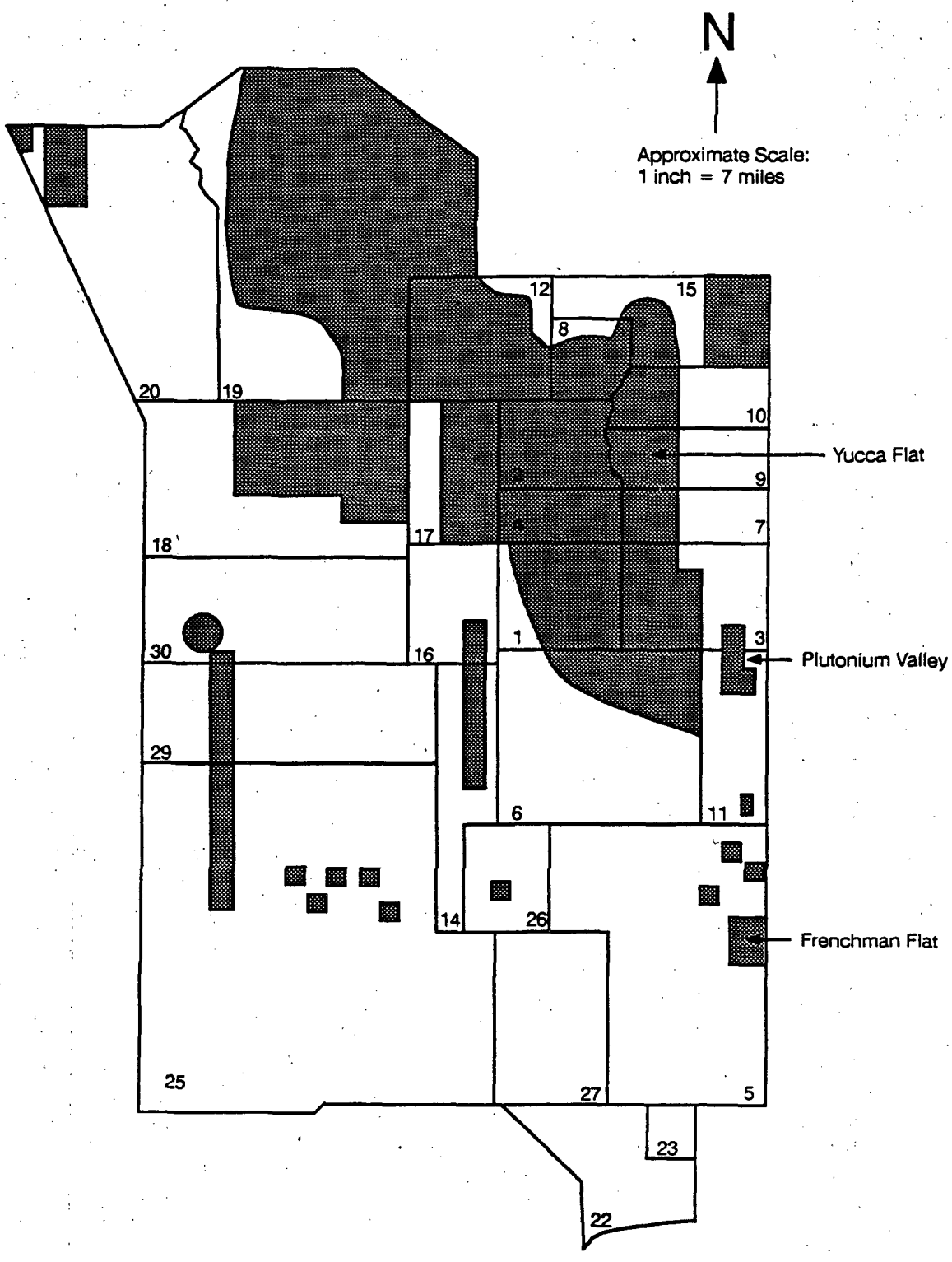


Figure 1. Portions of the NTS surveyed by the RIDP.

During each measurement, pulses from gamma rays reaching the detector were sorted into a 4096-channel energy spectrum. At the end of the 15-minute count period, the spectrum was transferred to the computer, where a spectral analysis program computed the concentrations of various radionuclides. Finally, the spectrum was transferred to magnetic tape for further analysis.

For most surveys, the locations of the *in situ* measurements were specified in

feet apart. In the early surveys, an irregular pattern of grid points was measured that reflected the isopleths of exposure rate derived from the aerial survey results. In later surveys, complete rectangular grids were measured to simplify the data analysis, though the grid

The soil samples were usually collected at sites of *in situ* measurements located along two perpendicular transects through the GZ, if one was present. At most sites, a profile of four samples to a total depth of 15 cm was collected using the pit–scoop method described in Report 1. At a few sites such as Sedan, where it was suspected that radioactivity extended deeper into the soil, six increments were collected to a depth of 30 cm. The samples were dried and homogenized, then seived through a 10–mesh (1.7–mm) screen. Only the fine fraction was analyzed.

All samples were analyzed by gamma spectrometry to determine radionuclide depth distributions. The activity of each radionuclide was assumed to decrease exponentially with depth, with the rate of decrease characterized by an inverse relaxation length (α). The method for calculating inverse relaxation lengths from the gamma–spectrometry results varied during the course of the project, as described in Reports 1, 3, and 4.

Average values of the calculated inverse relaxation lengths for each radionuclide were used as parameters in the GAMANAL analysis of the *in situ* measurements. In many surveys, the depth distributions in the region near a GZ were different from those farther away. The measurements from the GZ region were therefore analyzed using a different set of inverse relaxation lengths. The inverse relaxation length values used in GAMANAL are summarized in Table 3.

A few top–increment soil samples from each survey were analyzed radiochemically for ^{90}Sr, ^{238}Pu, $^{239,240}Pu$, ^{137}Cs, and ^{241}Am. The ratios of ^{90}Sr to ^{137}Cs, ^{238}Pu to ^{241}Am, and $^{239,240}Pu$ to ^{241}Am were then calculated. Average values of these ratios, listed in Table 4, were used to estimate the inventories of ^{90}Sr, ^{238}Pu, and $^{239,240}Pu$ from the estimated inventories of ^{137}Cs and ^{241}Am.

A set of procedures for quality assurance (QA) was part of the analytical protocol for all soil samples except those from the Galileo area. These procedures, carried out under the direction of E. Essington at Los Alamos National Laboratory, included analyses of hidden replicate samples, analyses of reference blind and background samples, and interlaboratory comparisons. The results were presented in appendices to the last four RIDP reports. Two separate reports will summarize the QA procedures (Essington and Mead, in preparation) and results (Essington, in preparation).

RESULTS

Radionuclide Inventories

Table 5 gives the estimated inventories of the nine most important manmade radionuclides in surface soil in each NTS area. All inventory values except those of ^{241}Am, ^{238}Pu, and $^{239,240}Pu$ are decay–corrected to January 1, 1990.

The estimates in Table 5 are based on the inventory estimates from the individual surveys published in the previous reports. However, all of the earlier estimates were reevaluated for this report, and many of them were revised.

TABLE 3. INVERSE RELAXATION LENGTHS (1/cm) USED IN GAMANAL ANALYSES

Location		α_1	α_2	α_3	α_4	α_5
Galileo	GZ	0.6	0.4	0.4	0.05	0.6
	others	0.6	0.4	0.4	0.3	0.6
Kepler	GZ	0.6	0.4	0.4	0.05	0.6
	others	0.8	0.4	0.4	0.3	0.6
Whitney	GZ	0.8	0.1	0.4	0.05	0.6
	others	0.8	0.4	0.4	0.3	0.6
Diablo	GZ	0.8	0.4	0.4	0.05	0.6
	others	0.8	0.4	0.4	0.3	0.6
Baneberry		0.6	0.6	0.6	0.3	0.6
Smoky	GZ	0.6	0.1	0.4	0.05	0.6
	others	0.6	0.4	0.4	0.3	0.6
Sedan	GZ	0.05	0.05	0.05	0.05	0.05
	others	0.4	0.4	0.4	0.3	0.4
Oberon		0.6	0.4	0.6	0.05	0.6
Wilson	GZ	0.6	0.1	0.4	0.05	0.6
	others	0.6	0.4	0.4	0.3	0.6
Quay	GZ	1.0	0.05	1.0	0.05	1.0
	others	1.0	0.4	1.0	0.4	1.0
Hornet	GZ	0.4	0.05	0.3	0.05	0.4
	others	0.4	0.4	0.4	0.3	0.4
Pahute Mesa		0.4	0.4	0.4	0.4	0.4
Schooner	GZ	0.1	0.1	0.1	0.1	0.1
	others	0.6	0.6	0.6	0.6	0.6
Cabriolet		0.4	0.4	0.4	0.4	0.4
Johnie Boy	GZ	0.1	0.1	0.1	0.1	0.1
	others	0.4	0.4	0.4	0.4	0.4
Little Feller I	GZ	0.1	0.1	0.1	0.1	0.1
	others	0.5	0.5	0.5	0.5	0.5
Little Feller II	GZ	0.5	0.5	0.5	0.5	0.5
	other	0.1	0.1	0.1	0.1	0.1
Danny Boy	GZ	0.05	0.05	0.05	0.05	0.05
	others	0.3	0.3	0.3	0.3	0.3
Areas 25 & 26		0.3	0.05	0.3	0.05	0.3
Area 15		0.6	0.6	0.6	0.6	0.6
Buggy	GZ	0.2	0.2	0.2	0.2	0.2
	others	0.5	0.5	0.5	0.5	0.5
Areas 17 & 18		0.4	0.4	0.4	0.4	0.4
Areas 12 & 19		0.1	0.1	0.1	0.1	0.1
Plutonium Valley		0.6	0.6	0.6	0.6	0.6
Pinstripe & GMX		0.5	0.05	0.5	0.05	0.5
Frenchman Lake	GZ	0.1	0.05	0.1	0.05	0.1
	others	0.4	0.05	0.4	0.05	0.4

Note: α_1 used for ^{241}Am, ^{238}Pu, $^{239,240}Pu$
α_2 used for ^{60}Co, ^{101}Rh, ^{102m}Rh, ^{125}Sb
α_3 used for ^{137}Cs
α_4 used for ^{133}Ba, ^{134}Cs, ^{152}Eu, ^{154}Eu
α_5 used for ^{155}Eu, ^{174}Lu

TABLE 4. AVERAGE RADIONUCLIDE RATIOS

Location	$^{90}Sr/^{137}Cs$	$^{238}Pu/^{241}Am$	$^{239,240}Pu/^{241}Am$
Galileo	1.5	not reported	5.0
Kepler	1.3	2.0	6.0
Whitney	2.7	3.2	9.9
Diablo	2.0	2.7	5.6
Baneberry	0.25	0.69	3.9
Smoky	2.5	0.72	7.2
Sedan	0.82	1.0	5.5
Oberon	1.6	0.13	6.7
Wilson	1.9	0.52	21.
Quay	2.2	0.26	7.5
Hornet	3.3	0.70	8.1
Schooner	0.95	1.7	0.69
Cabriolet	1.0	1.95	0.90
Palanquin	0.93	0.93	2.6
Johnie Boy	5.2	1.9	11.
Little Feller I & II	2.0	0.12	5.7
Danny Boy	0.63	0.12	4.0
Areas 25 & 26	0.84	0.20	6.5
Area 15	1.4	1.3	6.8
Buggy	0.97	1.4	4.4
Areas 17 & 18	1.5	1.6	6.3
Areas 12 & 19	0.97	1.5	6.8
Plutonium Valley	0.58	0.14	5.9
Pinstripe	0.88	1.04	5.8
GMX	0.56	0.14	7.2
Kay Blockhouse	0.86	0.39	9.2
RWMS	0.68	0.29	7.9
Frenchman Lake	2.6	0.31	8.2

One reason for revising the estimates was the inconsistent treatment in previous reports of upper limit values (ULVs). If the GAMANAL program was unable to find the peaks associated with a particular radionuclide, it calculated a ULV from the integrated background counts in the energy window where the peak should have been. In many regions far from a GZ, most of the measurement results were ULVs. Such regions obviously had low concentrations, but they often covered a large area and so could contain a substantial part of the total inventory.

In some of the previous reports, inventories were not estimated at all for regions where most of the results were ULVs, leading to an underestimate of the total inventory. In the others, the ULVs were treated as actual measurements, leading to an overestimate. To make the treatment of ULVs consistent and more accurate, the following rules were applied in estimating the inventory in these regions:

TABLE 5. ESTIMATED INVENTORIES OF MAJOR MANMADE RADIONUCLIDES IN NTS SURFACE SOIL AS OF JANUARY 1, 1990

	Radionuclide Inventory (Ci)								
Area	^{241}Am	^{238}Pu	^{239,240}Pu	^{60}Co	^{137}Cs	^{90}Sr	^{152}Eu	^{154}Eu	^{155}Eu
1	4.2	6.5	24.	1.1	8.8	15.	15.	0.1	0.5
2	2.9	8.6	22.	1.2	24.	46.	14.	0.	0.4
3	4.6	3.1	37.	1.0	12.	33.	18.	0.1	0.5
4	6.6	13.	40.	1.6	12.	13.	9.1	0.	0.2
5	0.6	0.1	4.8	0.6	0.4	0.9	10.	0.2	0.
6	1.7	3.3	8.4	0.2	2.8	3.5	0.	0.	0.
7	2.2	0.6	16.	1.0	5.2	9.2	22.	0.2	0.3
8	17.	8.0	110.	5.7	42.	25.	4.4	0.	0.6
9	4.2	2.2	89.	0.7	8.7	13.	23.	0.2	0.3
10	19.	19.	110.	9.7	84.	55.	2.2	0.3	5.0
11	3.3	0.5	29.	0.	0.5	0.3	0.	0.	0.
12	5.7	8.5	39.	1.2	20.	17.	0.	0.	0.
15	8.0	7.8	63.	0.3	19.	22.	0.	0.	0.
16	0.7	1.5	3.7	0.1	2.9	3.7	0.	0.	0.
17	2.8	4.5	18.	1.0	15.	19.	0.	0.	0.
18	19.	5.6	100.	0.7	10.	17.	1.1	0.1	0.8
19	21.	32.	140.	1.1	36.	31.	0.	0.	0.
20	23.	30.	41.	7.9	5.5	4.3	13.	1.6	4.8
25	0.	0.	0.	0.	0.2	0.1	0.4	0.	0.
26	0.	0.	0.	0.	0.	0.	0.	0.	0.
30	3.2	4.5	14.	0.8	1.5	1.3	0.7	0.1	0.2
Total	150.	160.	910.	35.	310.	330.	130.	2.8	14.

1. ^{137}Cs was almost always present in measurable amounts, so the few ULVs were treated as valid data.

2. ^{241}Am and ^{60}Co were assumed to be present at one-half the ULV, as determined by inspection of the data. For example, if the ^{241}Am values in a region tended to be ULVs in the 25 to 35 nCi/m^2 range, a value of 15 nCi/m^2 was assumed.

3. The three europium isotopes were found only relatively close to a GZ. They were assumed not to be present at all in regions where only ULVs were reported. Some previous inventory estimates for these radionuclides were therefore not used in making Table 5.

Inventories of the plutonium isotopes and ^{90}Sr were estimated from ^{241}Am and ^{137}Cs inventories using the radionuclide ratios from the nearest GZ area.

Additional recalculation was necessary for Yucca Flat because the original estimates in Reports 1, 2, and 3 were not made for separate NTS areas.

The values in Table 5 also incorporate estimates for the unsurveyed parts of the NTS areas containing the mountains around Yucca Flat that were inaccessible to the RIDP vehicles. The unsurveyed parts of other areas (Areas 5, 6, 11, 16, 18, 20, 25, 26, and 30) are assumed to have negligible amounts of soil contamination from NTS activities, as are the areas not listed in Table 5 (Areas 14, 22, 23, 27, and 29). The total area for which inventories are estimated is about 500 square miles, roughly 40 percent of the total area of the NTS.

Appendix A describes in detail how the estimates in Table 5 were calculated. Several errors in the previously reported results for Areas 8 and 18 are corrected in Appendix C.

Most of the radionuclides listed in Table 1 are not found in global fallout at levels high enough to be measured with the methods used in the RIDP. All occurrences of these radionuclides on the NTS are therefore assumed to result from NTS activities. An exception is ^{137}Cs, which was present in surface soil southwest of the NTS (upwind) at levels of 30 to 60 nCi/m^2 in the early 1980s (McArthur and Miller, 1989). If the average concentration of ^{137}Cs on the NTS due to global fallout is 35 nCi/m^2 as of January 1, 1990, then about 46 Ci of the 210 Ci of ^{137}Cs reported in Table 5 is from global fallout. The fraction of ^{90}Sr due to

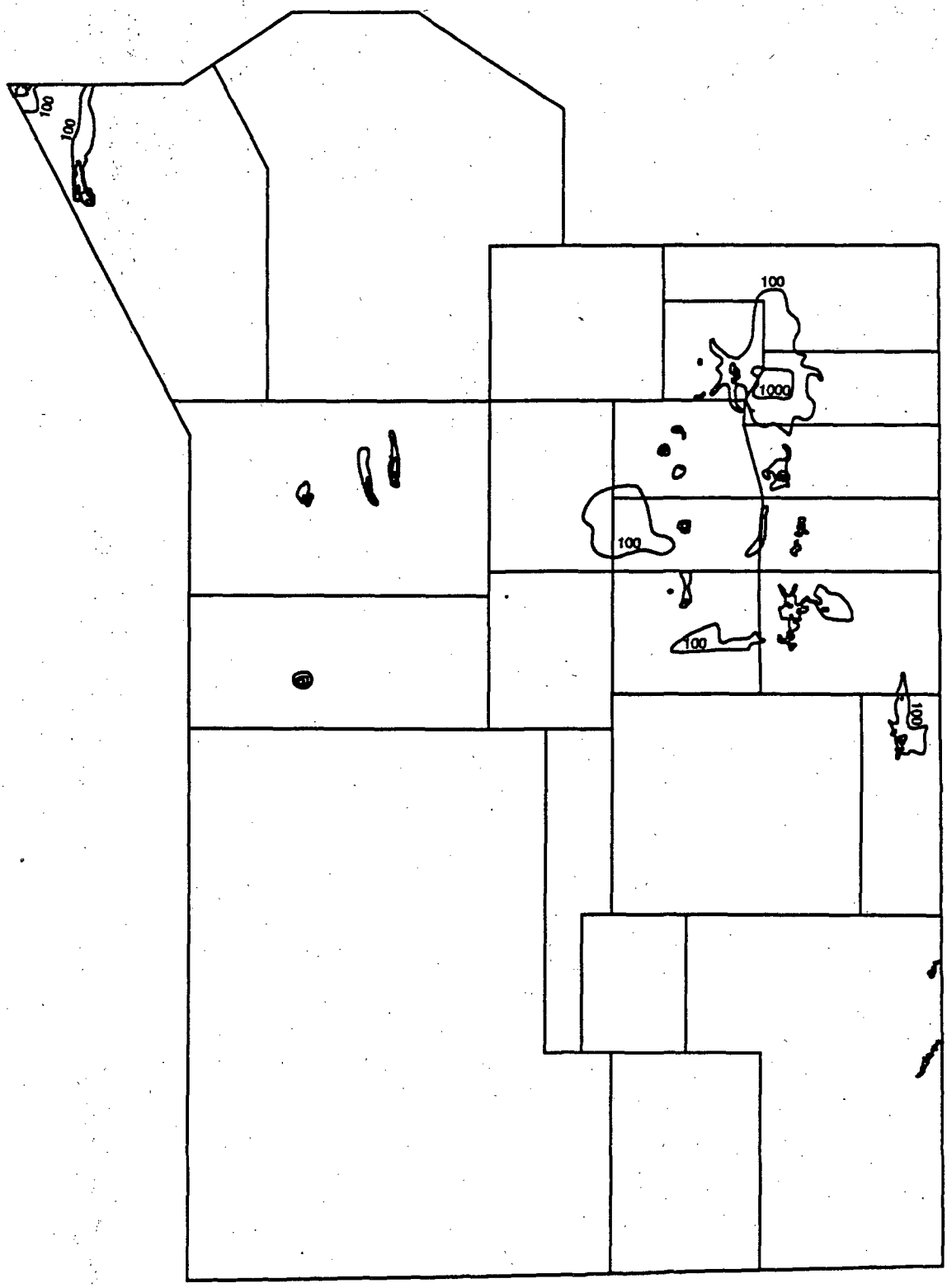


Figure 2. Distribution of ^{241}Am on the NTS as of January 1, 1990. Isopleth levels are 100, 1,000, and 10,000 nCi/m^2.

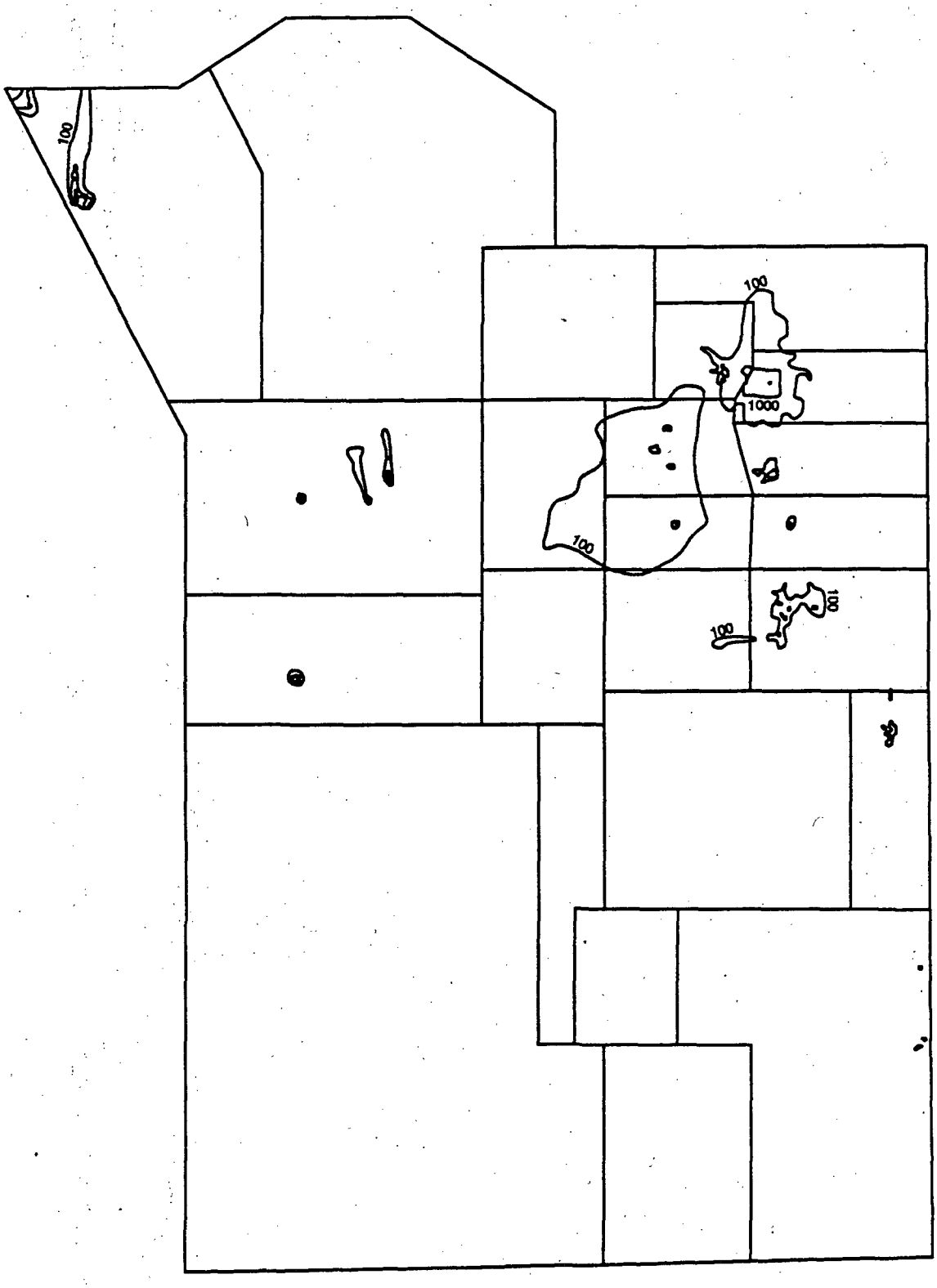


Figure 3. Distribution of ^{238}Pu on the NTS as of January 1, 1990. Isopleth levels are 100, 1,000, and 10,000 nCi/m^2. No measurements of ^{238}Pu were made in the Galileo area in Area 1.

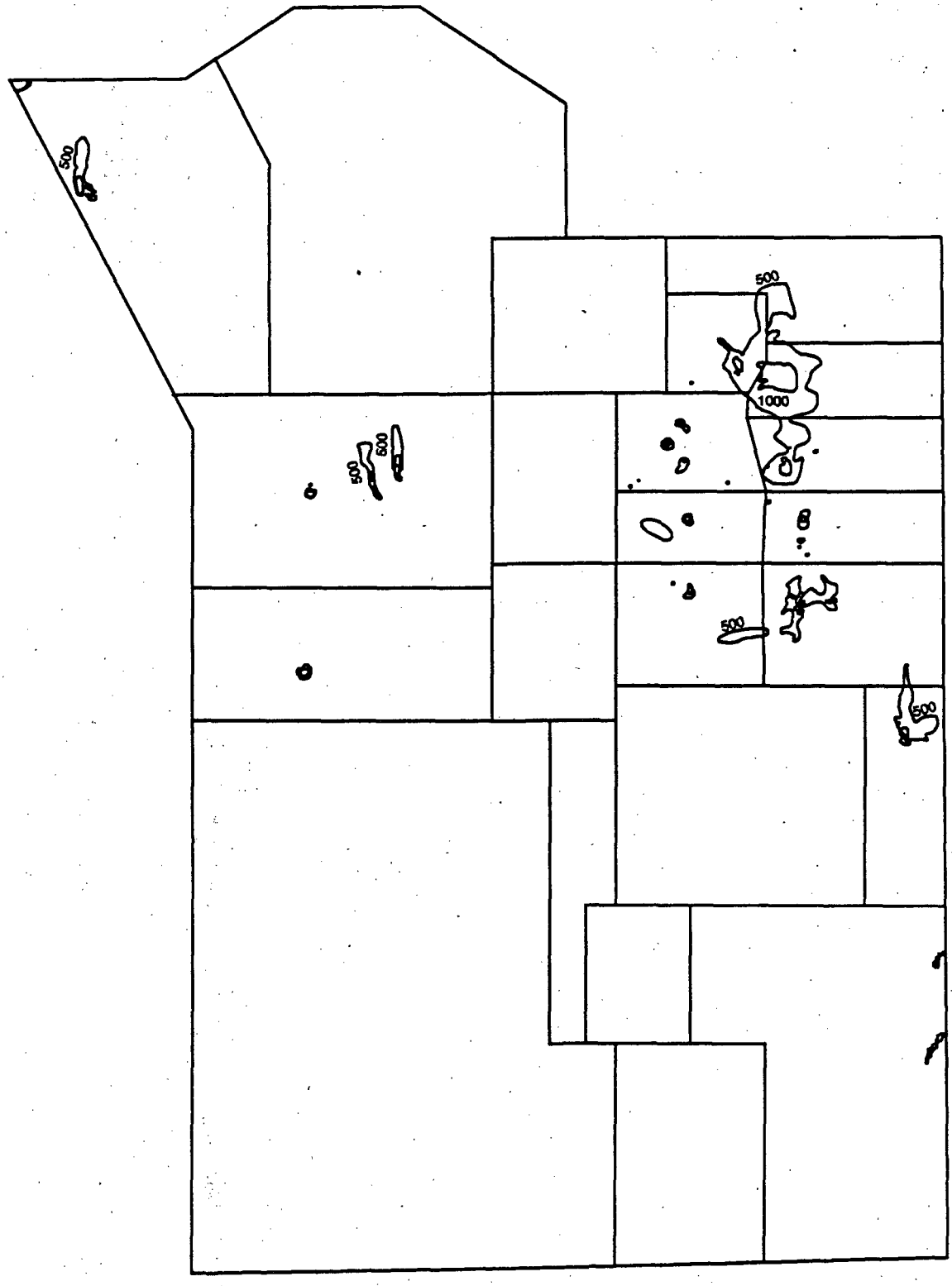


Figure 4. Distribution of $^{239,240}Pu$ on the NTS as of January 1, 1990. Isopleth levels are 500, 1,000, and 10,000 nCi/m^2.

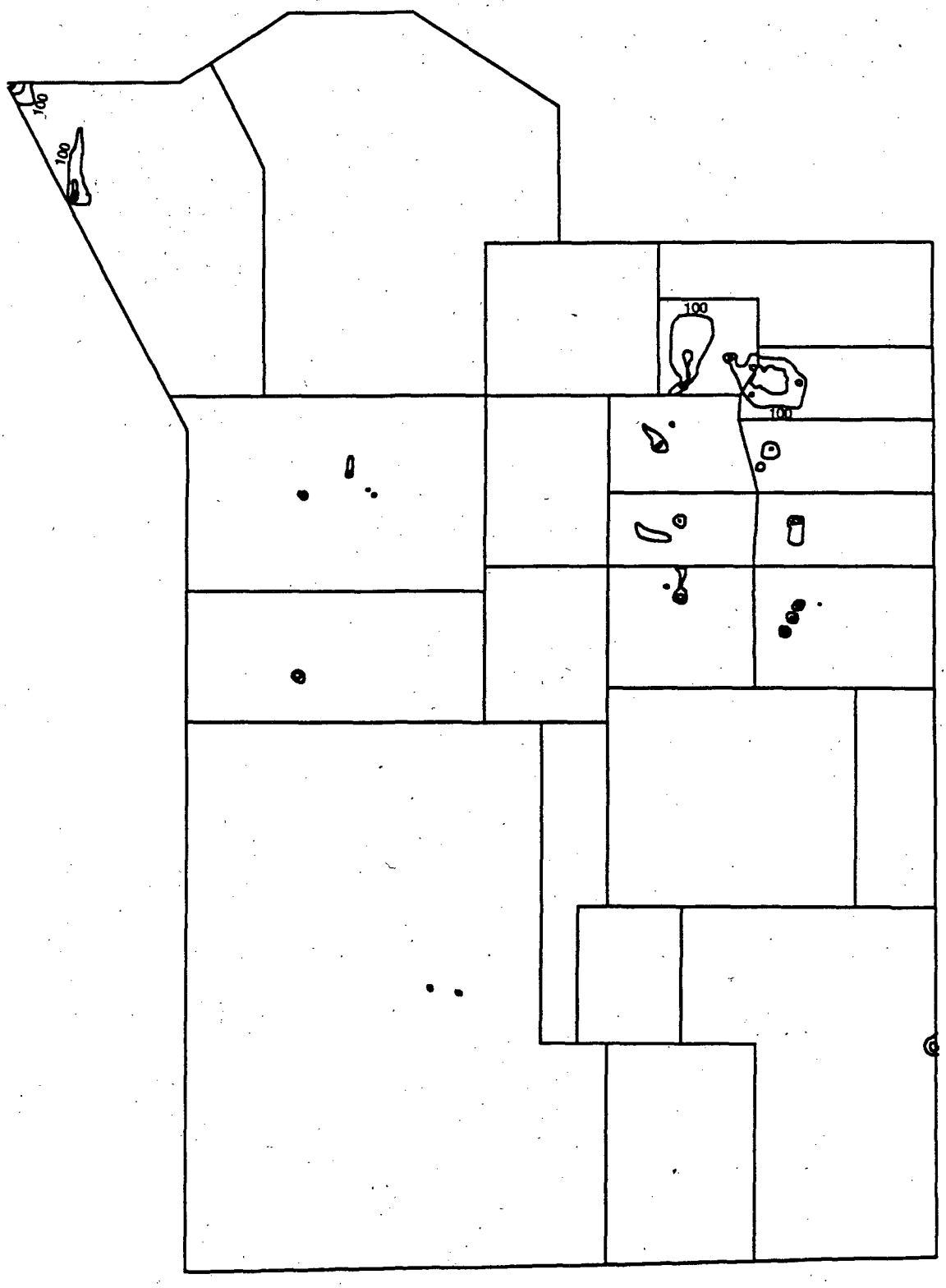


Figure 5. Distribution of ^{60}Co on the NTS as of January 1, 1990. Isopleth levels are 100, 1,000, and 10,000 nCi/m^2.

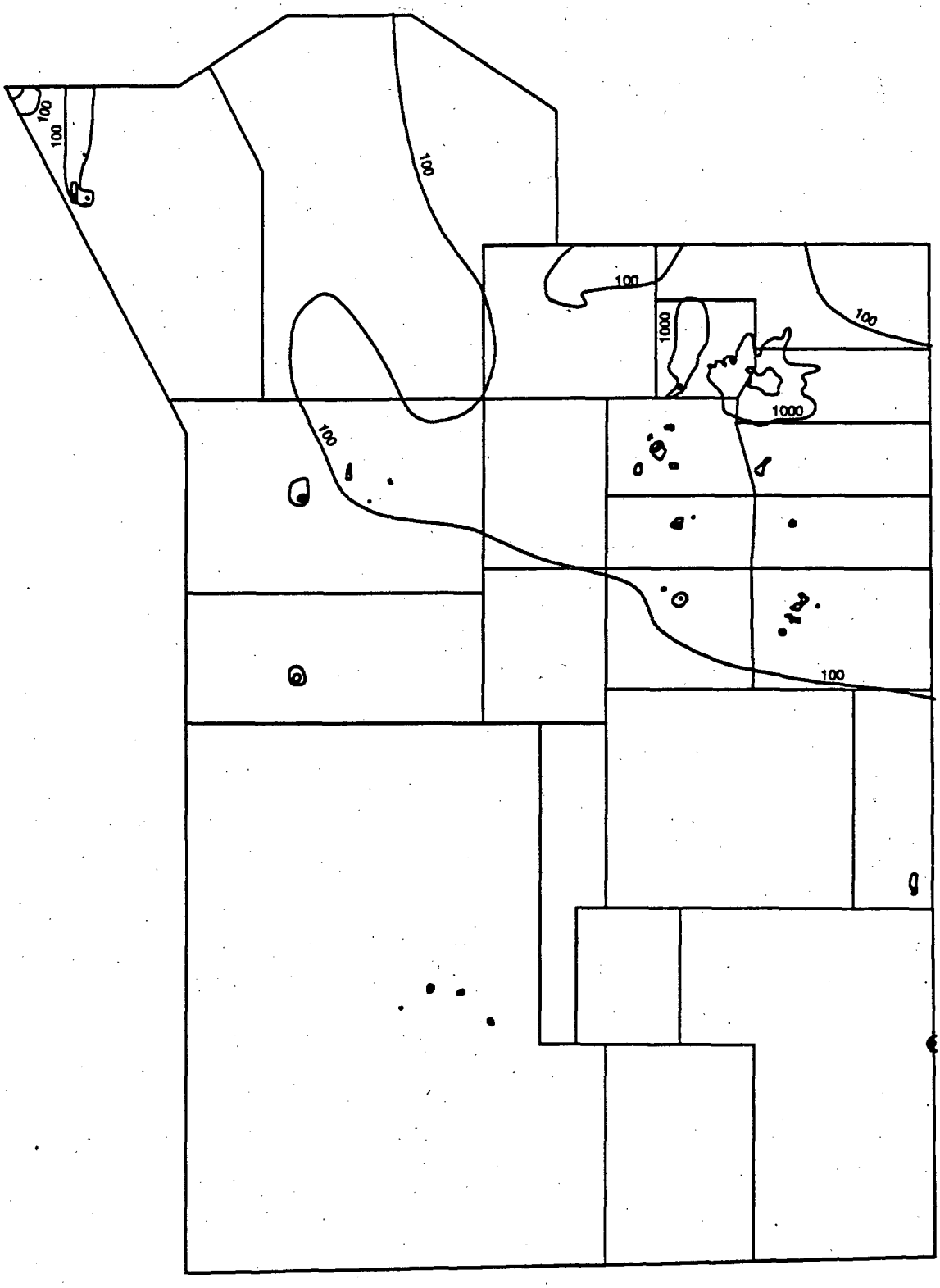


Figure 6. Distribution of ^{137}Cs on the NTS as of January 1, 1990. Isopleth levels are 100, 1,000, and 10,000 nCi/m^2.

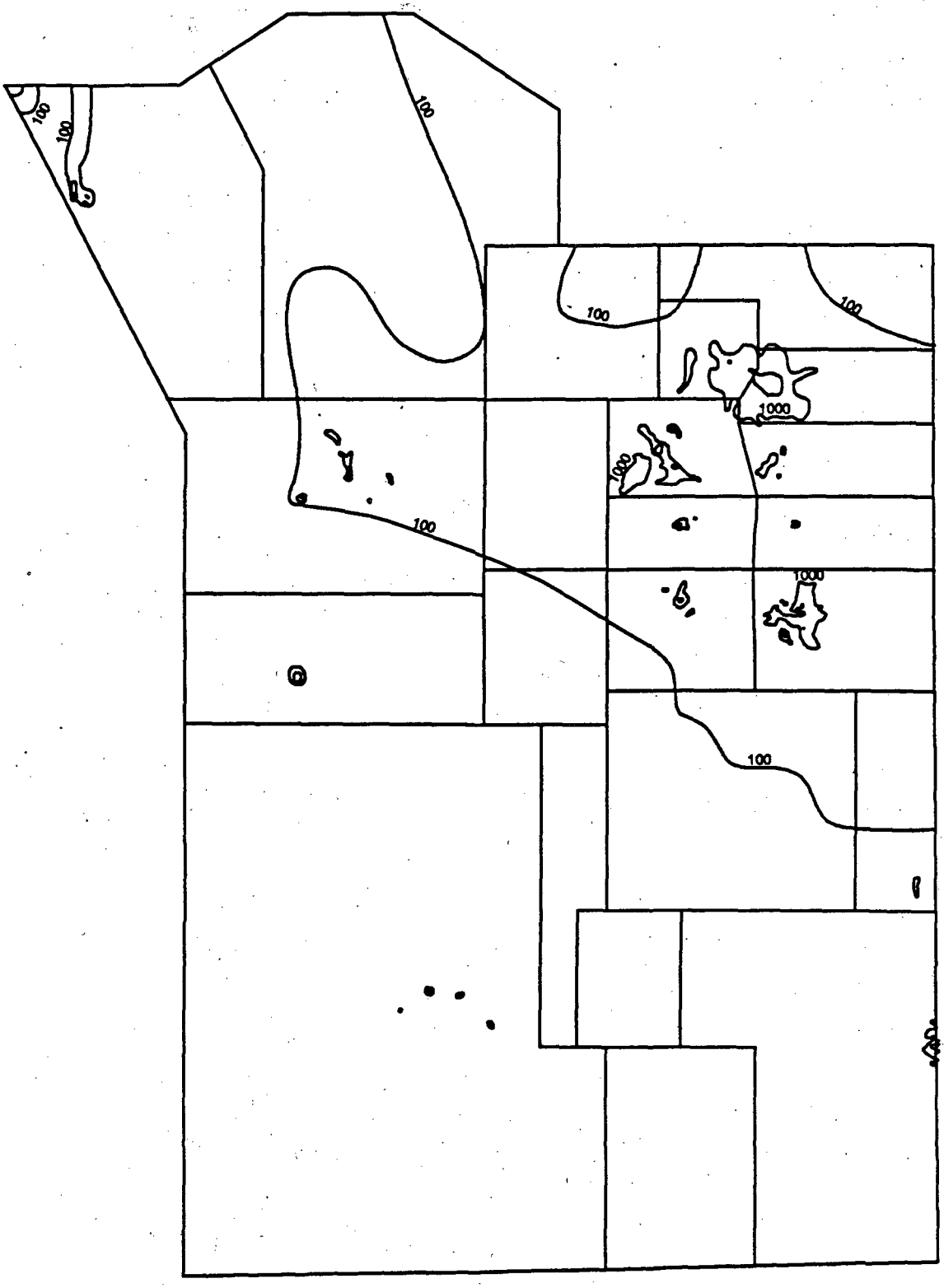


Figure 7. Distribution of ^{90}Sr on the NTS as of January 1, 1990. Isopleth levels are 100, 1,000, and 10,000 nCi/m^2.

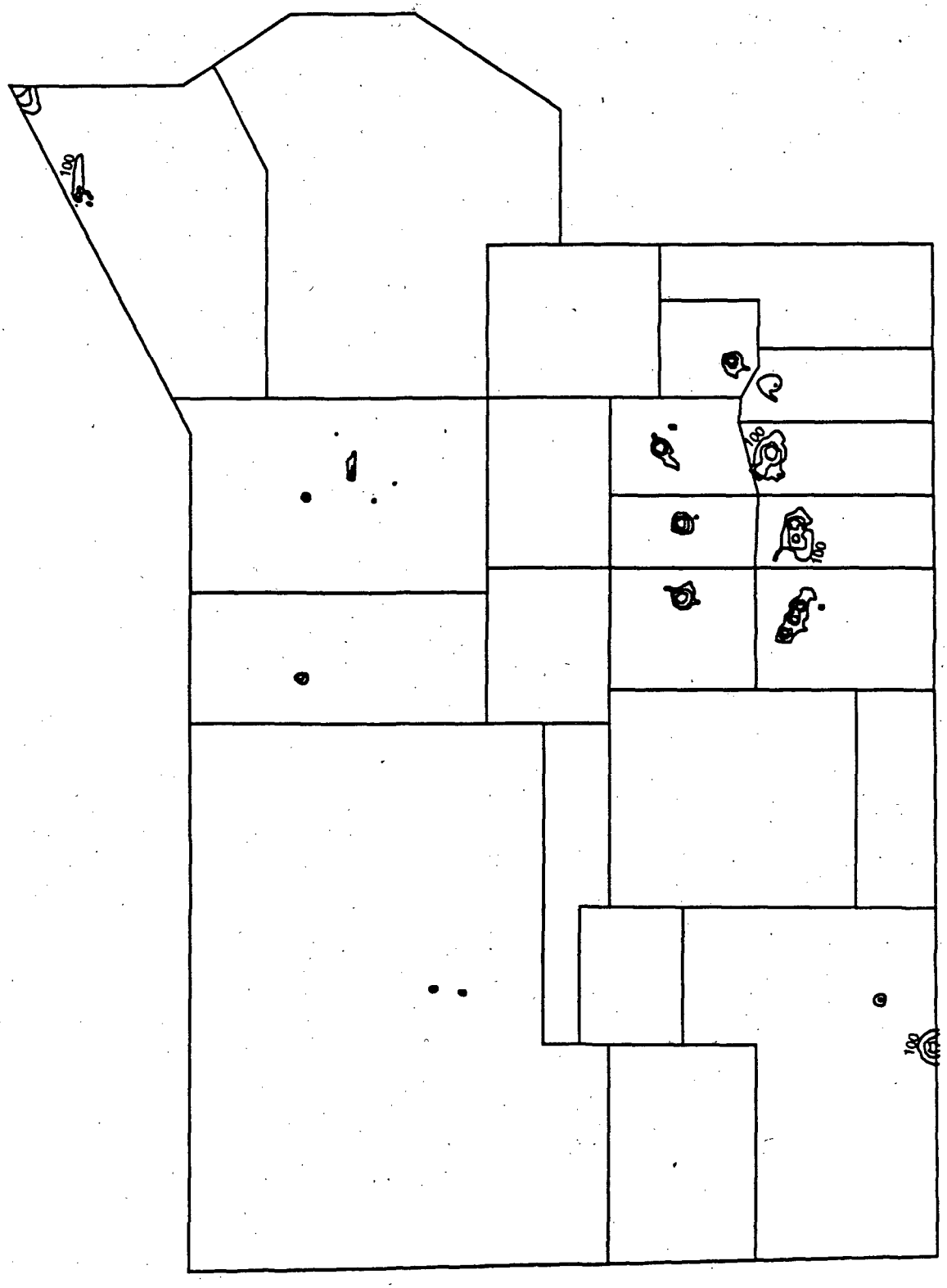


Figure 8. Distribution of ^{152}Eu on the NTS as of January 1, 1990. Isopleth levels are 100, 1,000, and 10,000 nCi/m^2.

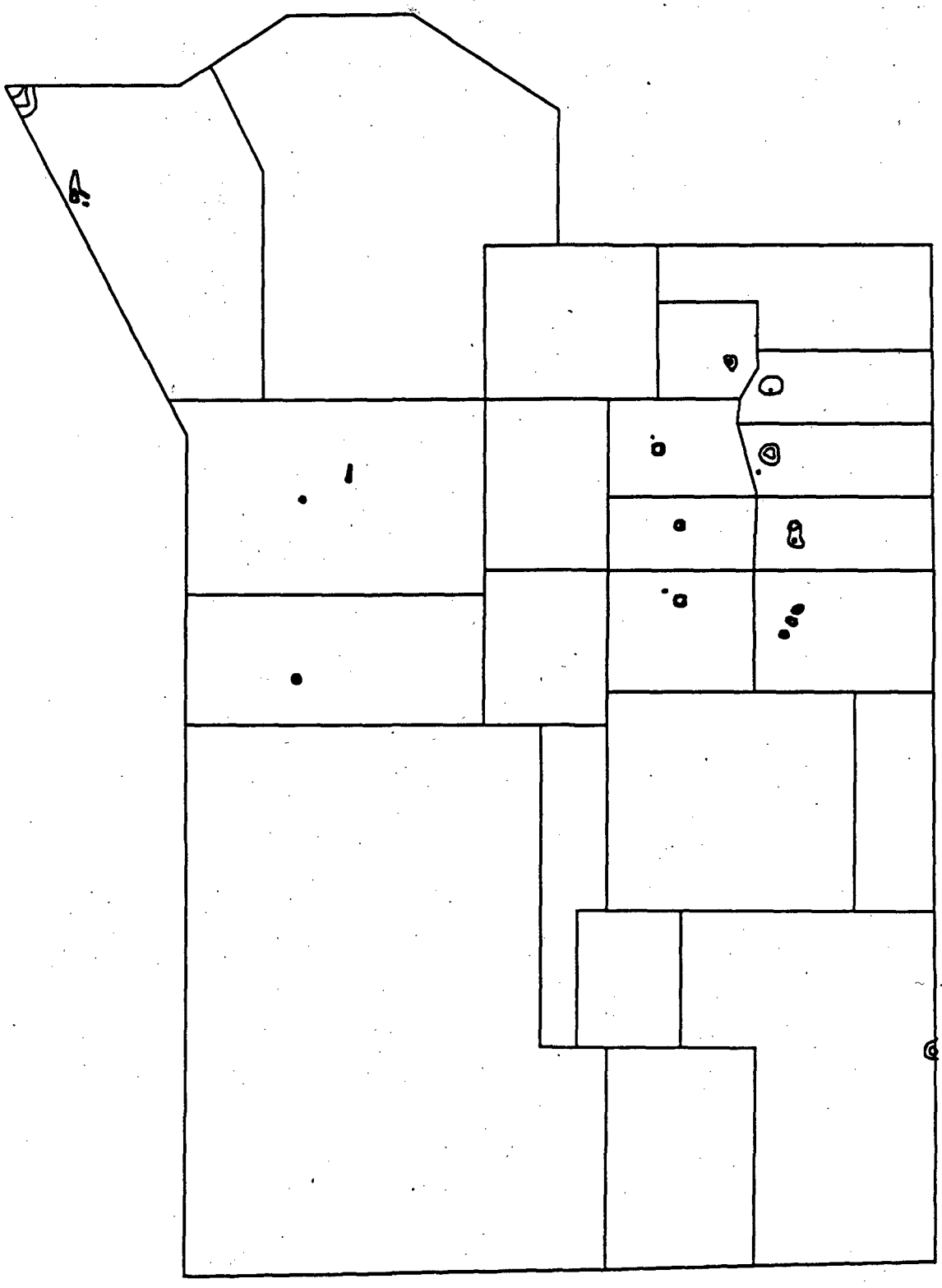


Figure 9. Distribution of ^{154}Eu on the NTS as of January 1, 1990. Isopleth levels are 100, 1,000, and 10,000 nCi/m^2.

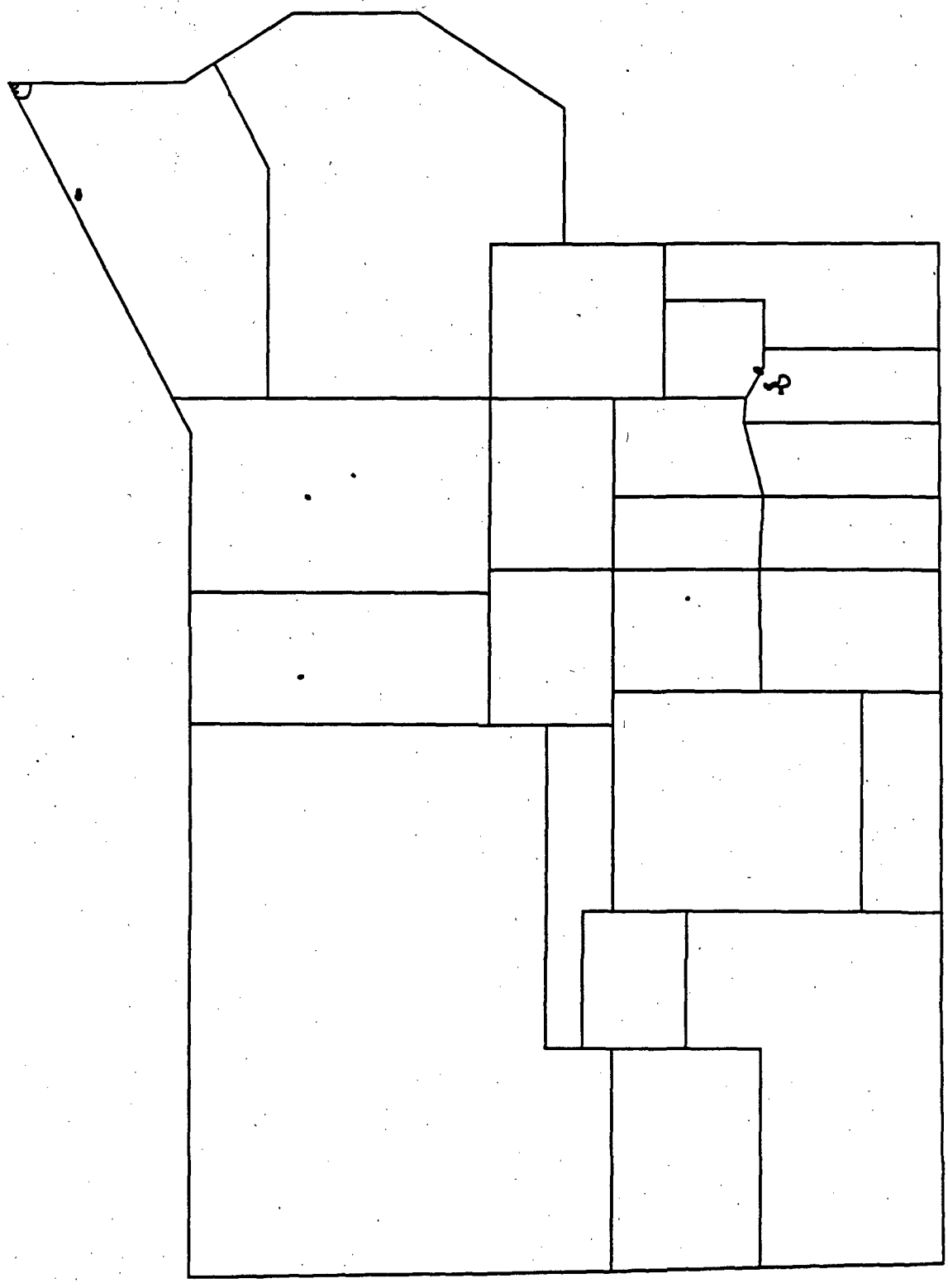


Figure 10. Distribution of ^{155}Eu on the NTS as of January 1, 1990. Isopleth levels are 100, 1,000, and 10,000 nCi/m^2.

Figures 2 through 10 are only intended to give a general picture of the overall distribution of soil radioactivity on the NTS. The small size of most contaminated areas relative to the size of the NTS makes it impossible to label most of the isopleths without obscuring this picture. The values of any unlabeled isopleth can be inferred by using the following guidelines:

- Isopleths are drawn for 100 nCi/m^2, 1,000 nCi/m^2, and 10,000 nCi/m^2 for all radionuclides except ^{239,240}Pu, where a 500 nCi/m^2 isopleth replaces the 100 nCi/m^2 one. (Because the ^{239,240}Pu to ^{241}Am ratio exceeds 5 in most areas and the smallest ^{241}Am measurements are around 40 nCi/m^2, few calculated ^{239,240}Pu values are less than 200 nCi/m^2.)

- The general distribution pattern is the same for all radionuclides. In the southern and western parts of the NTS, concentrations are less than 100 nCi/m^2 except in isolated areas. Only ^{137}Cs and ^{90}Sr exceed 100 nCi/m^2 over a broad region in the northeast corner.

- All isopleths behave "normally," with larger-valued isopleths contained within smaller-valued ones.

Larger-scale, more detailed maps for any contaminated region can be found in the five RIDP reports.

Exposure Rate

The total exposure rate from gamma radiation at each location was calculated by first [redacted]

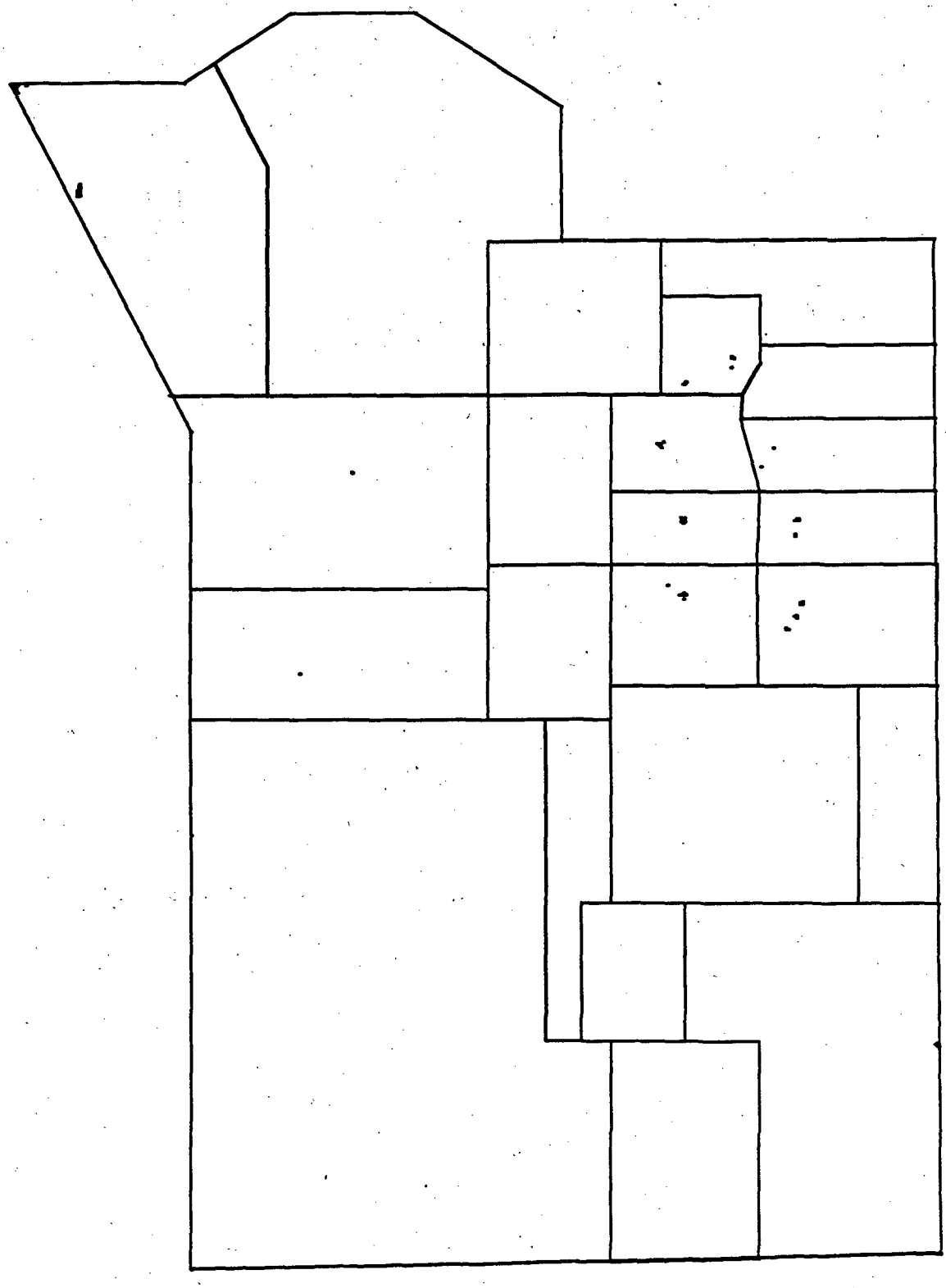


Figure 11. Locations of *in situ* measurements where the exposure rate exceeds 100 μR/h.

[redacted]

concentration exceeds 500 pCi/g. The highest values are near the Oberon GZ in Area 8, where two measurements exceed 100,000 pCi/g (the maximum is 320,000 pCi/g). Four other points at Oberon, one at Wilson, one at Quay, and four at Little Feller II exceed 10,000 pCi/g.

The highest concentration calculated for a Plutonium Valley location was 3,000 pCi/g. However, concentrations are undoubtedly much higher in the immediate vicinities of the four blast centers. Also, substantial amounts of plutonium are known to be present in the soil in regions outside the NTS boundary at Frenchman Lake (Area 5) and the Schooner site (Area 20).

UNCERTAINTY OF THE RESULTS

The project operations plan (Kordas and Anspaugh, 1982) specified an overall goal of providing "a final inventory that is known with 95% confidence within at least a factor of two." The project scientists feel that this level of precision has been attained, but this assessment derives more from their expert judgment than from any numerical analysis. The process by which the inventory estimates are produced is complex, and uncertainty enters it at a number of points. A thorough evaluation of how these uncertainties interact to affect the precision of the final results is not currently practicable.

Sources of Uncertainty

Listed below are the major sources of uncertainty in the inventory estimates and distribution maps and an indication of their importance.

Counting error. The random nature of radioactive decay is an intrinsic source of variation in any measurement of radioactivity. The GAMANAL program calculates the counting error as a percentage of the activity of each radionuclide. Reported values typically

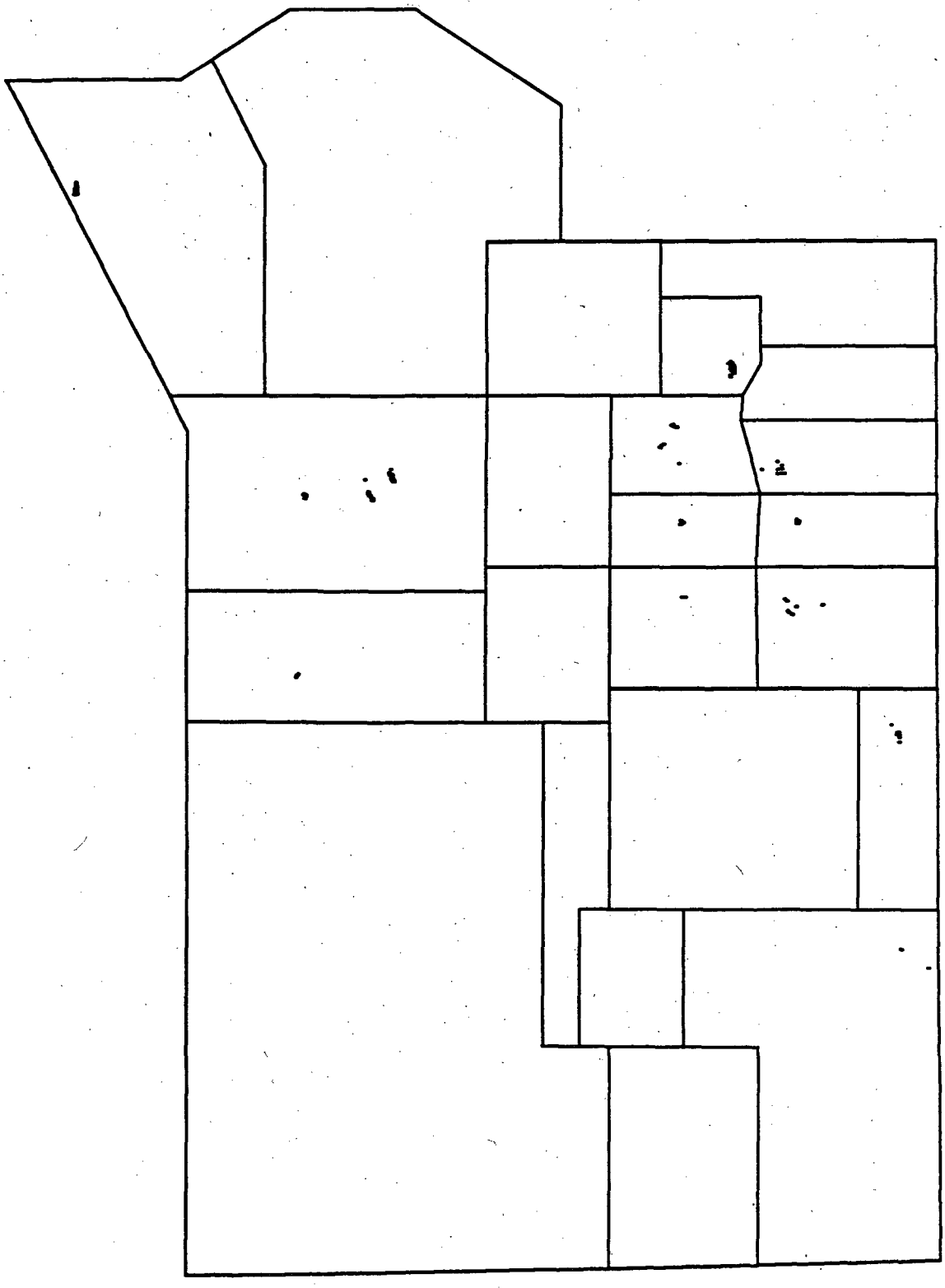


Figure 12. Locations of *in situ* measurements where the $^{239,240}Pu$ level exceeds 500 pCi/g.

Radionuclide ratios. The ratios used to estimate inventories of ^{238}Pu, $^{239,240}Pu$, and ^{90}Sr were averages of values measured in soil samples. The number of samples involved was usually small, and the variability in the measured ratios was usually large, so the values used to estimate inventories have a high uncertainty. Errors in the ratios affect the inventory estimates directly, so if the average ratio is too high by 50 percent, the inventory estimate will also be too high by 50 percent.

Upper Limit Values. When ULVs were used in a data set, they were treated as valid measurements, so the resulting estimates are larger than they should be. The areas within which inventories were estimated were usually set up to include as few ULVs as possible, so the error involved in the total inventory figures is probably negligible.

Sampling error. Sampling error results from estimating the total inventory in an area from measurements at relatively few locations. The size of the sampling error depends on the distribution of radioactivity in the area, the number of measurements, and how the measurement locations are chosen.

The only RIDP study areas where the sampling variability can be estimated directly are the four GZs in Area 18, where importance sampling was used to select the measurement locations (Report 4). The sampling standard deviation at these sites ranged from 5 percent to 40 percent of the total inventory.

Most of the other GZ areas were sampled on a regular grid, with 400–foot or 500–foot grids being used in the regions of highest activity. The sampling variability of the grid design at Frenchman Lake was estimated to be about 20 percent (Report 5, pp. 46–48), and the variability at similar GZ areas is probably comparable. The sampling variability is probably somewhat larger at safety shot sites like those in Plutonium Valley, where contamination occurs in discrete particles that are typically not as uniformly distributed around the GZ as is the radioactivity from a fission explosion.

Location. The locations of the *in situ* measurements were usually determined with a microwave ranging system. The errors in the computed locations can be anywhere from 10 feet to 250 feet or more, depending primarily on the relative positions of the location and the two microwave transponders. The effect of such errors on the inventory estimates and distribution maps is hard to determine, but it is believed to be relatively small compared to other uncertainties.

Comparison with Earlier Studies

During the course of the RIDP, surveys were made of four regions that had previously been studied by researchers from the Nevada Applied Ecology Group (NAEG). The estimates of $^{239,240}Pu$ inventory obtained by both groups for these regions are shown in Table 6. While the estimates are not entirely comparable because of differences in the areas surveyed, the comparison is still of some interest.

TABLE 6. RIDP AND NAEG ESTIMATES OF ^{239,240}PU INVENTORY

Region	Size of Region (km^2)		Inventory (Ci)	
	RIDP	NAEG	RIDP	NAEG
GMX	0.97	0.13	1.4	1.5
Plutonium Valley	8.7	4.8	29	36
Palanquin/Cabriolet	12	~3.4	48*	13*
Little Feller II	0.87	1.1	27	25 to 31

*Includes ^{241}Am inventory

References: RIDP Reports 4 and 5; Gilbert, 1977; Gilbert *et al.*, 1985.

GMX. The NAEG estimate was based on the analysis of 111 soil samples. Of the 65 RIDP *in situ* measurements at GMX, 8 were within the NAEG study area. Using the average of these eight measurements and a ^{239,240}Pu/^{241}Am ratio of 7.2 (the average from three RIDP soil samples) leads to an estimate of 1.1 Ci of ^{239,240}Pu in the NAEG area. If the NAEG's Pu/Am ratio of 10.3 (based on 89 samples) is used instead, the estimated inventory for the NAEG study area is 1.4 Ci, in good agreement with the NAEG estimate.

Plutonium Valley. The area surveyed by the RIDP includes all but the southern edge of the NAEG study area. The RIDP found a substantial amount of ^{239,240}Pu, about 7 Ci, north and east of the NAEG area. Consequently, the RIDP estimate for the NAEG area is about 22 Ci, somewhat less than the NAEG estimate. The NAEG estimate was based on 205 soil samples, while the RIDP estimate was based on 128 *in situ* measurements.

Palanquin/Cabriolet. The area surveyed by the RIDP was twice as large as that surveyed by the NAEG, which partly explains the difference in inventory estimates. In addition, the NAEG did not include the regions within 500 feet of the GZs in its survey. On the other hand, the NAEG was able to sample in the rocky area near the two GZs where the RIDP vehicle could not go. The difference in regions surveyed makes a detailed comparison of the data difficult.

Little Feller II. The original RIDP estimate in Report 4 was three times the NAEG estimate. Investigation of the discrepancy led to discovery of a major error in the calculations; see Appendix C for details. The corrected RIDP estimate (based on 54 *in situ* measurements) agrees closely with the NAEG estimate (based on analyses of 712 soil samples).

The results of these comparisons thus tend to confirm the accuracy of the *in situ* method as used in the RIDP.

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APPENDIX A
CALCULATION OF TOTAL RADIONUCLIDE INVENTORIES

Table 5 gives the total estimated inventories of nine radionuclides in each NTS area where contamination from NTS activities occurs. This appendix gives the details of how those numbers were obtained.

TABULATION OF RESULTS

The first step was to tabulate the inventory estimates on an area-by-area basis. About one-third of the estimates were obtained directly from tables in the earlier RIDP reports. Many others were modified from earlier results to make the treatment of upper limit values consistent. Also, the estimates for parts of Yucca Flat had to be recalculated to give estimates for the individual NTS areas.

In addition, inventory estimates were calculated for regions which could not be surveyed because of the terrain, but which were known to have some contamination from NTS activities. The average radionuclide concentrations assumed for these regions are listed in Table A-1.

TABLE A-1. AVERAGE RADIONUCLIDE CONCENTRATIONS ASSUMED FOR UNSURVEYED REGIONS

Region	Radionuclide Concentration (nCi/m^2)		
	^{241}Am	^{60}Co	^{137}Cs
West of Yucca Flat			
Area 1	30	4	50
Area 4	150	200	450
Area 2	75	100	400
East of Yucca Flat			
Areas 3, 7, 9	20	8	100
Area 10	30	20	500
North of Yucca Flat			
Area 8	30	300	700
Area 15	100	4	200
West side of Area 17	20	10	150

The tabulated inventory estimates are shown in Table A-2. The following notes give details of how these estimates were derived. Much of the discussion is in terms of average

concentrations of a radionuclide in a region. Inventories are estimated from the average and the area of the region by the formula:

$$I = \text{average activity } (nCi/m^2) \times \text{area } (mi^2) \times 0.0026,$$

where the .0026 factor converts nCi/m^2 to Ci/mi^2.

Area 1: The Galileo results are from the polygons of influence method using all the data, ULVs included (Table 9, Report 1). The Hornet region includes parts of regions HO–6 and QU–6 from Figure 3, Report 3; the calculations used the HO–6 averages. The South Yucca estimates used the average of the five grid points in Area 1. The same values were assumed for the unsurveyed part of Area 1 except that ^{241}Am was given a value of 30 nCi/m^2 instead of 60 because one South Yucca grid point had high ^{241}Am. No $^{238}Pu/^{241}Am$ ratio was reported for Galileo, so the Kepler value of 2.0 was used. The ratios used for the Galileo area were also used for South Yucca and the unsurveyed area.

Area 2: The Whitney, Shasta, and Diablo results are from Table 6 of Report 2, except that europium was assumed to be zero in the background regions. The remaining surveyed region includes parts of regions BA–3, SE–3, and WI–2 (Report 3); the average values were determined by inspection of the data. The values for the unsurveyed west side of Area 2 were derived from the Area 17 plots in Report 5. The average of the radionuclide ratios in 11 samples from the Whitney, Shasta, and Diablo areas (Table 3, Report 2) was used for the other two regions.

Area 3: The Hornet results are the combined inventories in regions HO–1 through HO–5 (Table 9, Report 3) plus contributions from regions QU–5, QU–6, and HO–6 determined by inspection of the data. The South Yucca values were based on the three Area 3 points. The averages of eight measurements east of the Hornet and Quay grids (Figure 2, Report 3) were used to estimate the inventories in the unsurveyed eastern parts of Areas 3, 7, and 9.

Area 4: The Kepler results are from Table 6 in Report 2; the ^{137}Cs value in Table A–2 is 0.2 Ci less than the value in Report 2 because a small part of the Kepler area is in Area 1. Europium was assumed to be absent from the background regions, but the ^{152}Eu inventory was rounded upward to reflect a small area of contamination east of the GZ area (Figure 7, Report 2). The Quay results are based on averages in the QU–6 region. The unsurveyed region was estimated from the four points on the western edge of the Kepler area.

Area 5: Results are from Tables 10 and 13 of Report 5.

TABLE A-2. ESTIMATED RADIONUCLIDE INVENTORIES

		Area	Radionuclide inventory (Ci)								
		(sq mi)	^{241}Am	^{238}Pu	$^{239,240}Pu$	^{60}Co	^{137}Cs	^{90}Sr	^{152}Eu	^{154}Eu	^{155}Eu
1	Galileo	4.8	1.0	2.0	5.0	2.8	4.8	7.2	21.3	2.2	0.6
	Hornet	5.7	1.3	0.9	10.2	0.1	3.5	11.7	0	0	0
	S. Yucca	7.6	1.2	2.3	5.9	0.1	1.0	1.5	0	0	0
	unsurveyed	8.4	0.7	1.3	3.3	0.1	1.1	1.6	0	0	0
		26.5	4.2	6.5	24.4	3.1	10.4	22.0	21.3	2.2	0.6
2	Whitney	2.7	0.4	1.4	4.8	1.6	4.0	11.2	19.4	0.7	0.1
	Shasta	4.9	0.7	2.1	5.3	0.7	10.4	27.0	0.3	0	0.3
	Diablo	4.0	1.0	2.7	5.6	0.4	9.0	18.0	0.4	0	0.1
	Sedan	6.1	0.4	1.2	3.3	0.2	3.2	7.9	0	0	0
	unsurveyed	2.0	0.4	1.2	3.2	0.5	2.1	5.2	0	0	0
		19.7	2.9	8.6	22.2	3.4	28.7	69.3	20.1	0.7	0.5
3	Hornet	8.5	3.4	2.3	27.1	1.8	8.5	28.1	24.4	1.1	0.6
	S. Yucca	4.6	0.2	0.1	1.5	0.1	0.6	2.0	0	0	0
	unsurveyed	19.2	1.0	0.7	8.1	0.4	5.0	16.4	0	0	0
		32.3	4.6	3.1	36.7	2.3	14.1	46.5	24.4	1.1	0.6
4	Kepler	9.7	5.8	11.6	34.8	3.9	10.8	14.0	13.0	0.9	0.2
	Quay	5.2	0.4	0.1	3.0	0.1	2.0	4.4	0	0	0
	unsurveyed	1.1	0.4	0.8	2.5	0.6	1.3	1.6	0	0	0
		16.0	6.6	12.5	40.3	4.6	14.1	20.0	13.0	0.9	0.2
5	Frenchman Lake	2.2	0.4	0.1	3.4	1.0	0.4	1.1	12.1	0.8	0
	GMX, etc.	0.7	0.2	0.0	1.4	0.0	0.0	0.0	0.2	0	0
		2.9	0.6	0.1	4.8	1.0	0.4	1.1	12.3	0.8	0
6	S. Yucca	32.3	1.7	3.3	8.4	0.4	3.3	5.0	0	0	0
7	Quay	6.7	1.5	0.4	11.2	2.1	2.8	6.1	29.9	2.4	0.4
	unsurveyed	12.6	0.7	0.2	4.9	0.3	3.3	7.2	0	0	0
		19.3	2.2	0.6	16.1	2.4	6.1	13.3	29.9	2.4	0.4
8	Baneberry	5.2	0.9	0.7	3.6	8.9	26.4	6.6	0	0	0
	Smoky	3.3	15.6	7.0	106.7	2.1	13.4	17.1	6.0	0.4	0.7
	unsurveyed	5.4	0.4	0.3	2.3	4.2	9.8	13.8	0	0	0
		13.9	16.9	8.0	112.6	15.2	49.6	37.5	6.0	0.4	0.7
9	Wilson	7.5	3.6	1.9	75.6	1.5	7.0	13.3	31.0	2.9	0.4
	unsurveyed	12.5	0.6	0.3	13.6	0.3	3.2	6.2	0	0	0
		20.0	4.2	2.2	89.2	1.8	10.2	19.5	31.0	2.9	0.4
10	Sedan	7.7	18.4	18.4	101.1	24.7	83.7	68.4	3.0	4.2	6.0
	unsurveyed	12.3	1.0	1.0	5.3	0.6	16.0	13.1	0	0	0
		20.0	19.4	19.4	106.4	25.3	99.7	81.5	3.0	4.2	6.0
11	Pu Valley	3.4	3.3	0.5	29.0	0.0	0.4	0.2	0	0	0
	Pinstripe	0.6	0.0	0.0	0.0	0.0	0.2	0.2	0	0	0
		4.0	3.3	0.5	29.0	0.0	0.6	0.4	0	0	0
12		39.6	5.7	8.5	38.5	2.2	22.0	21.0	0	0	0
15	Yucca Flat	4.3	2.5	2.1	21.3	0.3	8.8	12.1	0	0	0
	E side	12.2	0.6	0.8	4.3	0.0	2.2	3.1	0	0	0
	unsurveyed	18.8	4.9	4.9	37.2	0.2	9.8	13.7	0	0	0
		35.3	8.0	7.8	62.8	0.5	20.8	28.9	0	0	0
16	east half	14.3	0.7	1.5	3.7	0.1	3.2	4.7	0	0	0
17	Yucca Flat	11.2	1.8	2.8	11.3	1.4	9.2	14.0	0	0	0
	unsurveyed	20.2	1.0	1.7	6.6	0.5	7.3	11.0	0	0	0
		31.4	2.8	4.5	17.9	1.9	16.5	25.0	0	0	0
18	Little Feller I	0.6	6.0	0.7	33.6	0.3	0.3	0.5	0	0	0.1
	Little Feller II	0.3	4.7	0.6	27.0	0.0	0.3	0.6	0.1	0	0.1
	Johnie Boy	4.0	1.0	1.9	10.6	0.8	2.1	10.9	0.8	0.4	0.4
	Danny Boy	0.9	6.6	0.8	26.0	0.2	2.3	1.4	0.5	0.1	0.3
	NE corner	21.5	1.0	1.6	6.3	0.1	6.2	9.4	0	0	0
		27.3	19.3	5.6	103.5	1.4	11.2	22.8	1.4	0.5	0.9
19		148.3	21.2	31.8	144.2	1.9	39.9	38.7	0	0	0
20	Schooner	1.7	9.4	16.0	6.4	9.7	1.5	1.5	14.0	17.0	5.2
	Cabriolet	4.5	14.0	14.0	35.0	8.5	4.9	4.5	2.6	1.0	0.4
		6.2	23.4	30.0	41.4	18.2	6.4	6.0	16.6	18.0	5.6
25	NRDS	0.9	0.0	0.0	0.0	0.1	0.2	0.2	0.5	0	0
26	bunker	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
30	Buggy	0.3	3.2	4.5	14.1	1.4	1.7	1.6	0.9	0.4	0.2

Area 6: The estimates were made from 25 South Yucca measurements and the radionuclide ratios used for the Galileo area in Area 1.

Area 7: The Quay values include the inventories in regions QU–1 through QU–4 and contributions from WI–2, QU–5, and QU–6 (Table 9, Report 3). Inventories in the unsurveyed region were estimated as in Area 3.

Area 8: The Baneberry results include regions BA–1, BA–2, and 80 percent of BA–3, while the Smoky results include regions SM–1, SM–2, and 23 percent of SE–3 (Table 5, Report 3). Contamination from both ^{60}Co and ^{137}Cs extends north of the surveyed area at Baneberry, so relatively high levels were assumed for the unsurveyed region.

Area 9: The Wilson inventories are the sum of the reported inventories for region WI–1 and the portion of region WI–2 that is in Area 9 (Table 9, Report 3). Inventories in the unsurveyed region were estimated as in Area 3.

Area 10: The Sedan estimates are the sum of the estimates for regions SE–1 and SE–2 and 65 percent of the estimates for SE–3 (Table 5, Report 3). Averages in the unsurveyed region were estimated from the four easternmost Sedan points.

Area 11: Results are from Tables 7 and 13 in Report 5.

Area 12: Results for ^{60}Co, ^{137}Cs, and ^{90}Sr are from Report 5. The other estimates were calculated from an assumed level of 55 nCi/m^2 of ^{241}Am (see Table 19, Report 5).

Area 15: The results for Yucca Flat are from Report 5, as are most of the results from the east side. The ^{241}Am inventory for the east side is based on an assumed average level of 20 nCi/m^2. Elevated levels of radioactivity extend into the unsurveyed region north of Yucca Flat, so relatively high averages were used for that region.

Area 16: The aerial survey showed ^{137}Cs contamination in most of the eastern half of Area 16, so the average of the six ^{137}Cs measurements along the Mid–Valley Road (85 nCi/m^2) was used for the entire region. Assumed levels of 20 nCi/m^2 of ^{241}Am and 3 nCi/m^2 of ^{60}Co were used along with the ratios from the west side of Area 1 to estimate the other inventories.

Area 17: The Yucca Flat results are from Report 5. Contamination extends west of the surveyed area, so above–background levels were used for the unsurveyed area.

Area 18: Most of the estimates for the four GZ regions are from Table C–1 on page 43. All three europium isotopes are assumed to be absent from the regions north of the Little

Feller I and Johnie Boy GZs; ^{154}Eu is also assumed to be absent from the Littler Feller I and Little Feller II GZ areas. The estimates for ^{137}Cs and ^{90}Sr in the northeast corner of Area 18 are from Report 5. The remaining estimates were computed using assumed values of 18 nCi/m^2 of ^{241}Am and 2 nCi/m^2 of ^{60}Co and the ratios in Table 16 of Report 5.

Area 19: The ^{137}Cs and ^{90}Sr values are from Report 5. The other estimates were computed from assumed values of 55 nCi/m^2 of ^{241}Am and 5 nCi/m^2 of ^{60}Co and the average radionuclide ratios in Table 18, Report 5.

Area 20: Results are from Table 4 in Report 4.

Areas 25 and 26: Results are from Table 2 in Report 5. Because of the extensive cleanup of the contaminated sites in these areas, the inventories of ^{241}Am and plutonium were assumed to be insignificant.

Area 30: Results are from Table 4 in Report 5.

DECAY CORRECTION

After the inventory estimates had been tabulated, the totals for each area were decay-corrected to give the final estimates for Table 5. The formula for calculating the decay-corrected inventory I_c is

$$I_c = I_o \exp[-0.693t/t_h]$$

where I_o is the uncorrected inventory estimate, t is the time in years between the survey date and January 1, 1990, and t_h is the half-life of the radionuclide from Table 1. The survey date used for each area was the approximate date of the highest *in situ* measurements:

Survey	Date	Survey	Date
Galileo	12/01/81	Danny Boy	06/22/84
Kepler	10/08/81	Area 25	03/23/84
Whitney/Shasta	02/16/82	Area 26	03/28/84
Diablo	05/12/82	Area 17	11/20/84
Baneberry	06/29/82	Area 18	08/22/85
Smoky	10/04/82	Area 15 (Yucca)	10/23/84
Sedan	09/16/82	Area 15 (E side)	11/18/84
Wilson	12/02/82	GMX, RWMS,	
Quay	02/16/83	Kay blockhouse	02/01/85
Hornet	05/04/83	Pinstripe	02/01/85
South Yucca	06/01/83	Pu Valley	05/15/85
Schooner	10/05/83	Buggy	06/27/85
Cabriolet	08/24/83	Area 12	07/09/85
Johnie Boy	12/12/83	Area 19	07/30/85
Little Feller I	06/26/84	Area 16	09/17/85
Little Feller II	01/17/84	Frenchman Lake	10/22/85

Unsurveyed regions were given the date of the major survey in a given area. For example, the unsurveyed part of Area 3 was assigned the same date as the Hornet survey, May 4, 1983.

APPENDIX B
CALCULATION OF EXPOSURE RATE

The gamma–exposure rate at each location of an *in situ* measurement was calculated from the formula

$$\text{exposure rate} = \sum_{i=1}^{14} a_i X_i,$$

where X_i is the concentration (nCi/m^2) of radionuclide i and a_i is the factor for converting nCi/m^2 of radionuclide i to μR/h. The formula includes only 14 radionuclides because ^{90}Sr gives off no gamma radiation as it decays.

Conversion Factors

The conversion factor for a given radionuclide depends on the energy of the gamma rays it emits and its depth distribution in the soil, as characterized by the inverse relaxation length α. Table B–1 gives the conversion factors for the 14 radionuclides at the 9 different α values used in analyzing the *in situ* measurements.

TABLE B–1. CONVERSION FACTORS (μR/h per nCi/m^2)

	Inverse relaxation length (1/cm)								
Nuclide	**0.05**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.8**	**1.0**
^{241}Am	0.000035	0.000075	0.00011	0.00013	0.00015	0.00016	0.00017	0.00019	0.00021
^{133}Ba	0.0012	0.0015	0.0021	0.0028	0.0031	0.0034	0.0035	0.0039	0.0042
^{60}Co	0.0096	0.010	0.015	0.018	0.020	0.021	0.022	0.024	0.025
^{134}Cs	0.0030	0.0065	0.010	0.012	0.013	0.014	0.015	0.016	0.017
^{137}Cs	0.0012	0.0024	0.0035	0.0042	0.0047	0.0050	0.0053	0.0058	0.0062
^{152}Eu	0.0026	0.0048	0.0069	0.0080	0.0090	0.0098	0.0104	0.011	0.012
^{154}Eu	0.0026	0.0050	0.0075	0.0089	0.0099	0.0106	0.0113	0.0122	0.013
^{155}Eu	0.0001	0.00021	0.00032	0.00040	0.00044	0.00048	0.00051	0.00055	0.00059
^{174}Lu	0.00023	0.00043	0.00064	0.00075	0.00084	0.00090	0.00095	0.00103	0.00110
^{101}Rh	0.00055	0.00105	0.00174	0.00208	0.00235	0.00256	0.00273	0.0030	0.0032
^{102m}Rh	0.00083	0.0016	0.0023	0.0027	0.0030	0.0032	0.0036	0.0038	0.0040
^{125}Sb	0.00090	0.0018	0.0027	0.0032	0.0035	0.0038	0.0040	0.0044	0.0047
^{238}Pu	7.0×10^{-8}	9.0×10^{-8}	1.1×10^{-7}	1.4×10^{-7}	1.5×10^{-7}	1.7×10^{-7}	1.8×10^{-7}	2.1×10^{-7}	2.4×10^{-7}
$^{239,240}Pu$	1.6×10^{-7}	2.0×10^{-7}	2.7×10^{-7}	3.5×10^{-7}	4.0×10^{-7}	4.4×10^{-7}	4.6×10^{-7}	5.1×10^{-7}	5.6×10^{-7}

The factors for 11 radionuclides in Table B–1 were obtained from those given in Tables 1 and 2 of Beck (1980) and reproduced in Table B–2. Beck calculated conversion factors for various values of the relaxation length in g/cm^2; these values were converted into inverse relaxation lengths by dividing them into the soil density ρ, assumed to be 1.5 g/cm^3. Plots of conversion factor versus log α are nearly linear over the range of α values in Table B–2. Values of the conversion factors for the nine α values in Table B–1 were therefore obtained by interpolating and extrapolating from such plots.

TABLE B–2. CONVERSION FACTORS (μR/h per nCi/m^2) FROM BECK (*1980*)

Nuclide	relaxation length (g/cm^2) [inverse relaxation length (1/cm)][1] 1.6 [0.9375]	4.8 [0.3125]	16 [0.09375]
^{241}Am	0.000197	0.000136	0.0000710
^{60}Co	0.0254	0.0179	0.00992
^{134}Cs	0.0168	0.0118	0.00636
^{137}Cs	0.00615	0.00432	0.00231
^{152}Eu	0.0117	0.00817	0.00446
^{154}Eu	0.0127	0.00896	0.00488
^{155}Eu	0.000581	0.000397	0.000203
^{174}Lu	0.00109	0.000767	0.000416
^{101}Rh	0.00316	0.00212	0.00108
^{102m}Rh	0.00395	0.00272	0.00146
^{125}Sb	0.00461	0.00317	0.00169

[1]Calculated assuming a soil density of 1.5 g/cm^3.

Conversion factors for ^{133}Ba and plutonium are not given in Beck (1980). These factors were calculated as follows.

1. The energy and branching intensity of the gamma rays given off during the decay of each radionuclide were obtained from ICRP Publication 38 (International Commission on Radiological Protection, 1983). These values are shown in Table B–3. The gamma rays emitted by ^{240}Pu and other gamma rays of lower energy or branching intensity emitted by ^{239}Pu were judged to be insignificant and were omitted from the calculations.

2. Table 7 of Beck *et al.* (1972) gives exposure rates for various values of α/ρ and source energy, for a source strength of 1 gamma ray/cm^2–sec. The α/ρ values used in that table were multiplied by ρ = 1.5 g/cm^3 to give α values. The exposure rate was then plotted as a function of source energy for each of four values of α (Figure B–1).

3. For the energy of each gamma ray listed in Table B–3, linear interpolation and extrapolation from Figure B–1 were used to find the exposure rate at the four values of α. Figure B–2 shows a plot of the resulting values for ^{238}Pu. The exposure rates for the nine α values of interest were then obtained by linear interpolation and extrapolation from these four values. For example, at α = 0.5/cm, the 43–keV gamma ray gives an exposure rate of 0.073 μR/hr, while the 100–keV gamma ray gives 0.22 μR/hr.

TABLE B–3. ENERGY AND BRANCHING INTENSITY OF GAMMA RAYS

Nuclide	Energy (keV)	Branching Intensity (1/Bq•sec)
^{133}Ba	53.15	0.0217
	79.62	0.0256
	81.00	0.338
	160.6	0.00615
	223.2	0.00460
	276.4	0.0709
	302.9	0.184
	356.0	0.621
	383.9	0.0891
^{238}Pu	43.48	0.000389
	99.86	0.0000747
^{239}Pu	38.69	0.0000586
	51.62	0.000208
	98.81	0.0000130
	129.3	0.0000620
	203.5	0.00000560
	332.8	0.00000505
	345.0	0.00000561
	375.0	0.0000158
	380.2	0.00000307
	382.7	0.00000260
	393.1	0.00000444
	413.7	0.0000151
	451.4	0.00000192

4. For each value of α, the conversion factor for each gamma ray was computed from the exposure rate and the branching intensity B by the formula

$$\text{conversion factor} = \text{exposure rate} \times B \times 3.7\times10^{-3}.$$

The constant 3.7×10^{-3} has units of Bq•m^2•sec/nCi, so the conversion factor has units of (μR/hr)/(nCi/m^2).

5. The conversion factor for each radionuclide was obtained by adding the factors for the individual gamma rays. Thus for ^{238}Pu with α = 0.5/cm,

$$\begin{aligned} \text{43keV:}\quad & 0.073 \times .000389 \times 3.7\times10^{-3} &&= 1.05 \times 10^{-7} \\ \text{100 keV:}\quad & 0.22 \times .0000747 \times 3.7\times10^{-3} &&= \underline{0.61 \times 10^{-7}} \\ & &\text{Total} &= 1.66 \times 10^{-7} \end{aligned}$$

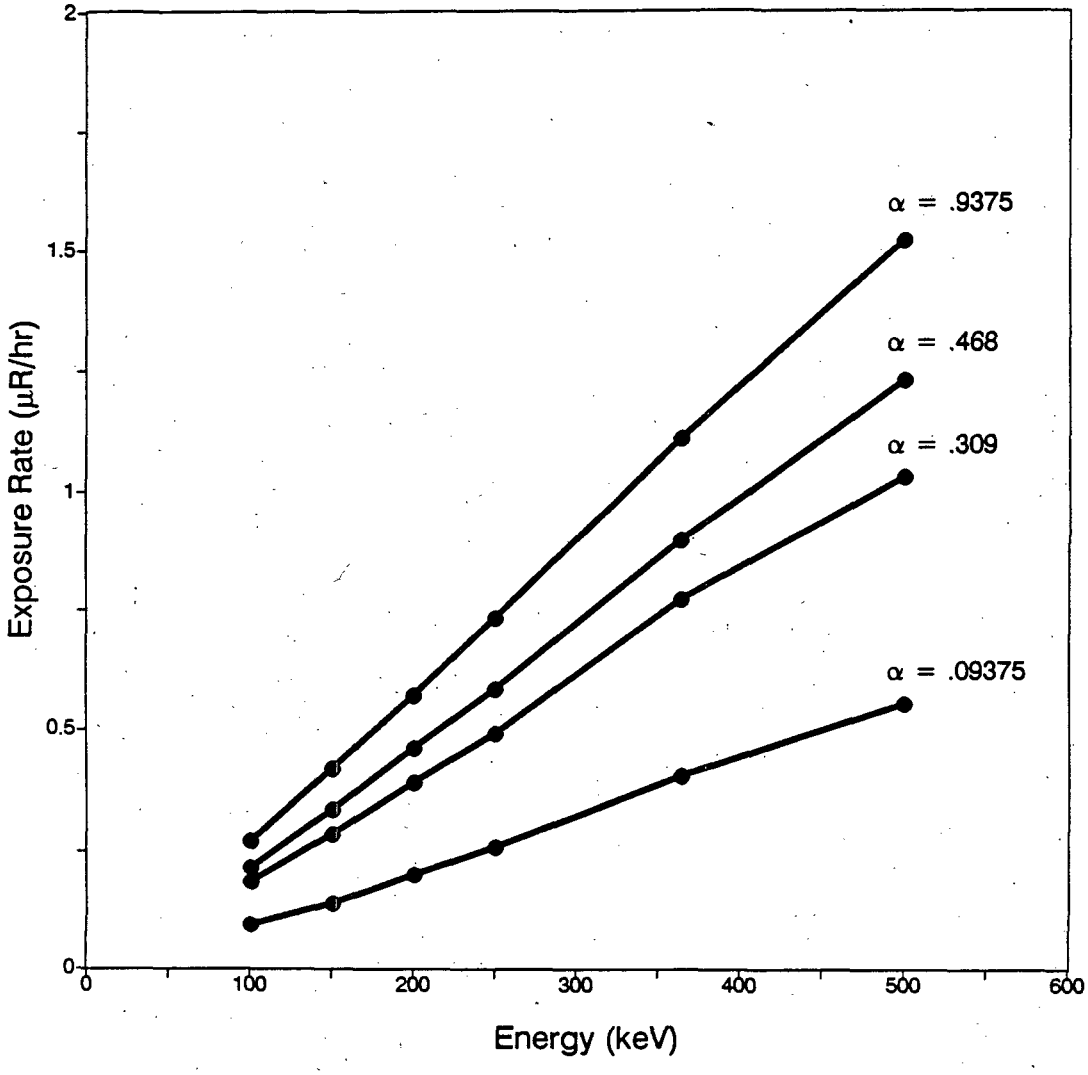


Figure B–1. Exposure rate as a function of energy for different depth distributions (data from Beck *et al.*, 1972).

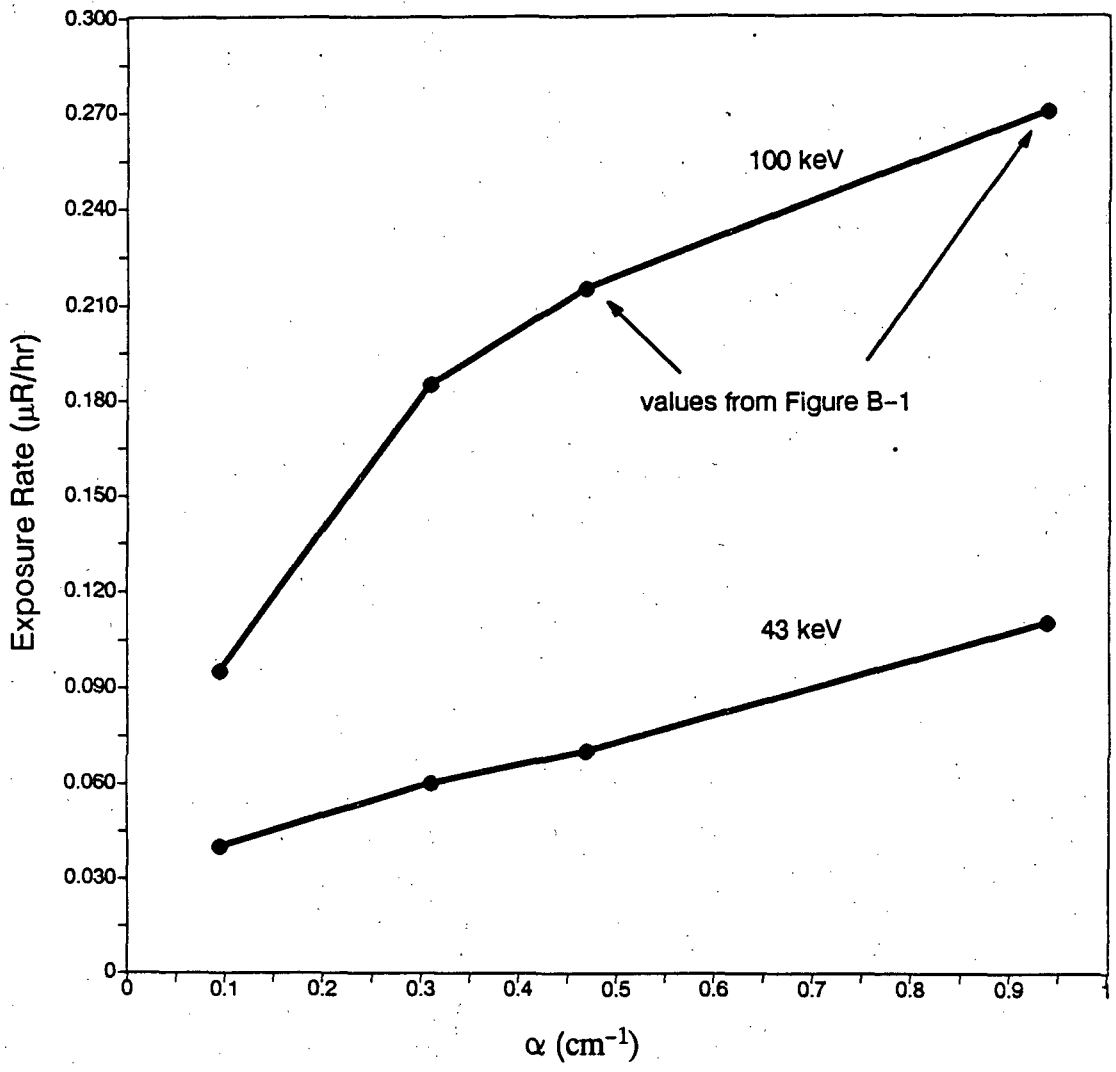


Figure B–2. Exposure rate as a function of α for ^{238}Pu gamma rays.

REFERENCES

Beck, H. L. 1980. Exposure rate conversion factors for radionuclides deposited on the ground. EML–378, Environmental Measurements Laboratory, U.S. Department of Energy, New York, N.Y.

Beck, H. L., J. Decampo, and C. Gogolak. 1972. *In situ* Ge(Li) and NaI(T1) gamma–ray spectrometry. HASL–258, Health and Safety Laboratory, U.S. Atomic Energy Commission, New York, N.Y.

International Commission on Radiological Protection. 1983. *Radionuclide Transformations: Energy and Intensity of Emissions.* ICRP Publication 38, Pergamon Press, New York.

APPENDIX C
CORRECTIONS TO PREVIOUS REPORTS

Report 3

In Table 5 on p. 21, the inventory of ^{90}Sr in Region BA-2 (Baneberry) was given incorrectly as 0.4 Ci. The correct value is 4.0 Ci.

Report 4

a. The labels on the Johnie Boy results in Table 7, p. 43, were switched. Table C-1 below is a corrected version of Table 7.

b. In Appendix A, the Nevada Grid Coordinates of the soil samples at the Little Feller II site are wrong. The right values, as obtained from the NAEG database, are given below.

	Coordinates	
Point	East	North
43	606117	862204
44	606342	862329
45	606167	862509
46	606042	862664
47	605941	862581
48	605852	862769
49	605867	862819
50	605667	862939
51	605797	863169

Earlier results for these samples were reported in Essington (1985).

Figure C-1 shows the true locations of the soil samples and the *in situ* measurements at Little Feller II. This figure is a revision of part of Figure 33 in Report 4.

Use of incorrect locations for the soil profiles resulted in inappropriate values of the inverse relaxation length being chosen for the GAMANAL analysis of the *in situ* measurements. Figure C-1 shows that seven of the nine profiles were from inside the GZ region and two were from outside. The averages of the calculated inverse relaxation lengths (from Table 5, Report 4) for the two most important radionuclides in each region are as follows:

	^{241}Am	^{137}Cs
inside GZ region	0.51/cm	0.55/cm
outside GZ region	0.11/cm	0.05/cm

The values used in the GAMANAL analysis were just the opposite: 0.1/cm for points in the GZ region and 0.5/cm for points outside.

Therefore, the concentrations of ^{241}Am and ^{137}Cs were recalculated using inverse relaxation lengths of 0.5/cm for the GZ region and 0.1/cm for the outside region. The general effect of this correction was to decrease the computed concentrations in the GZ region and increase those outside. The corrected values are plotted along with hand-drawn concentration isopleths in Figures C–2 and C–3.

Corrected inventory estimates are included in Table C–1, a revision of Table 7 in Report 4. The estimated ^{137}Cs inventory is essentially unchanged; the estimated ^{241}Am inventory, however, decreases by about a factor of three.

REFERENCES

Essington, E.H. 1985. Progress of soil radionuclide distribution studies for the Nevada Applied Ecology Group. In Howard, W.A., P.B. Dunaway, and R.G. Fuller, eds., *The Radioecology of Transuranics and Other Radionuclides in Desert Ecosystems*. NVO–224, U.S. Department of Energy, Nevada Operations Office, Las Vegas, pp. 145–184.

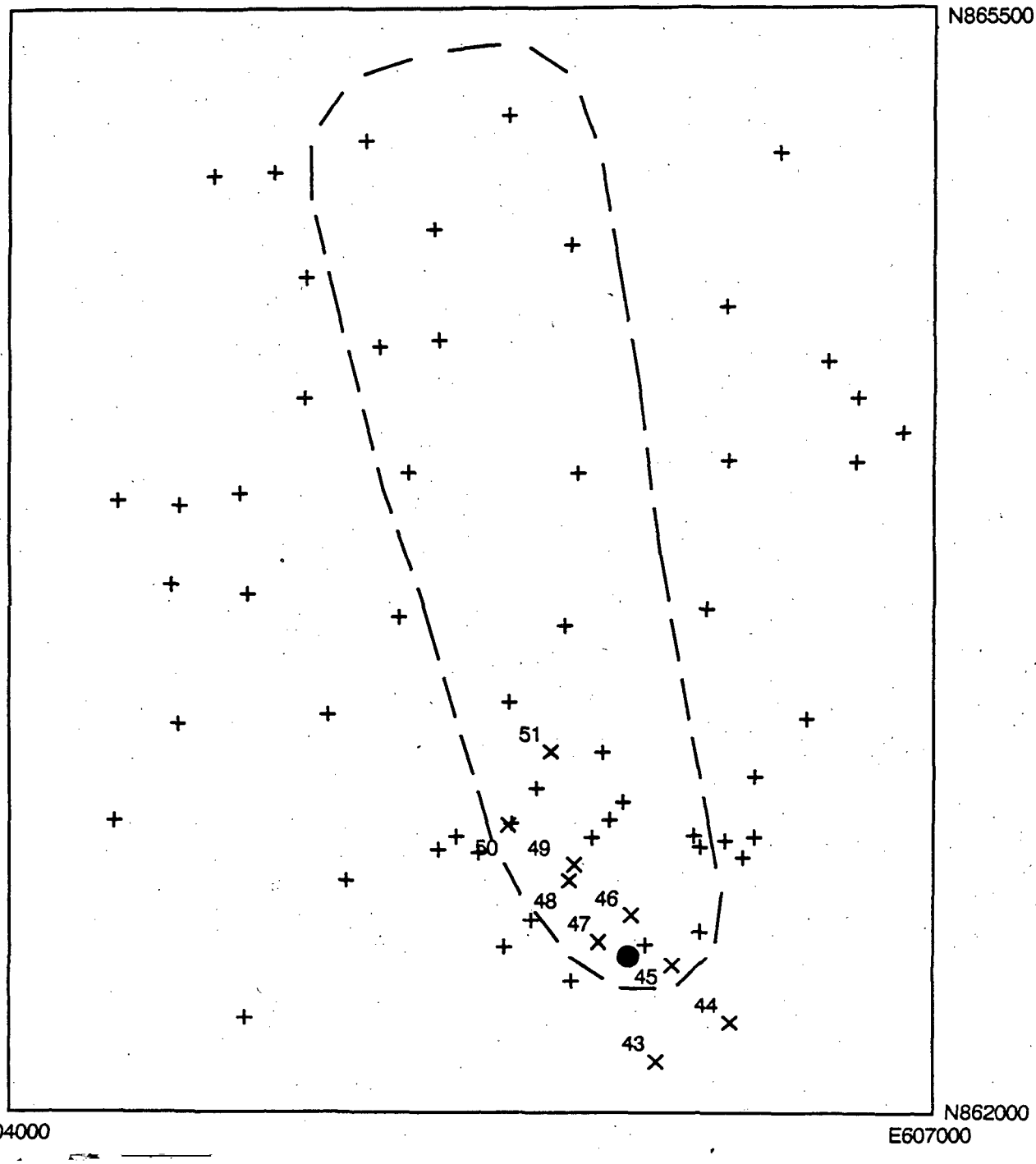
TABLE C-1. INVENTORY ESTIMATES FOR AREA 18

Region	Area ($ft^2 \times 10^6$)	Radionuclide Inventory ± Sampling S.D. (Ci)			
		^{241}Am	^{238}Pu	$^{239,240}Pu$	^{60}Co
Little Feller I					
GZ area	5.76	5.2 ± 1.9	.57 ± .21	29. ± 11.	.29 ± .16*
N of GZ	10.	.83	.091	4.6	.011*
Little Feller II	9.36	4.7 ± 1.4	.56 ± .17	27. ± 8.1	.034 ± .0027*
Johnie Boy					
GZ area	32.	.35 ± .025*	.67 ± .048	3.9 ± .28	.50 ± .092
N of GZ	79.	.61 ± .029*	1.2 ± .055	6.7 ± .32	.26 ± .015*
Danny Boy	24.64	6.6 ± 1.3	.79 ± .16	26. ± 5.2	.20 ± .037
Total	160.76	18. ± 2.7	3.9 ± .32	97. ± 15.	1.3 ± .19

TABLE C-1. INVENTORY ESTIMATES FOR AREA 18–Continued

Region	Radionuclide Inventory ± Sampling S.D. (Ci)				
	^{137}Cs	^{90}Sr	^{152}Eu	^{154}Eu	^{155}Eu
Little Feller I					
GZ area	.12 ± .018	.22 ± .032	.039 ± .0041*	.024 ± .0026*	.058 ± .0066*
N of GZ	.15	.27	.046*	.033*	.079*
Little Feller II	.29 ± .030	.58 ± .060	.10 ± .0078*	.10 ± .0088*	.11 ± .0077*
Johnie Boy					
GZ area	1.0 ± .10	5.2 ± .52	.78 ± .091	.41 ± .027	.35 ± .020
N of GZ	1.1 ± .071	5.7 ± .37	.60 ± .036*	.64 ± .035*	.58 ± .024*
Danny Boy	2.3 ± .29	1.4 ± .18	.53 ± .073	.13 ± .010	.27 ± .019*
Total	5.0 ± .32	13. ± .67	2.1 ± .12	1.3 ± .046	1.4 ± .038

*These estimates are based largely on upper limit values.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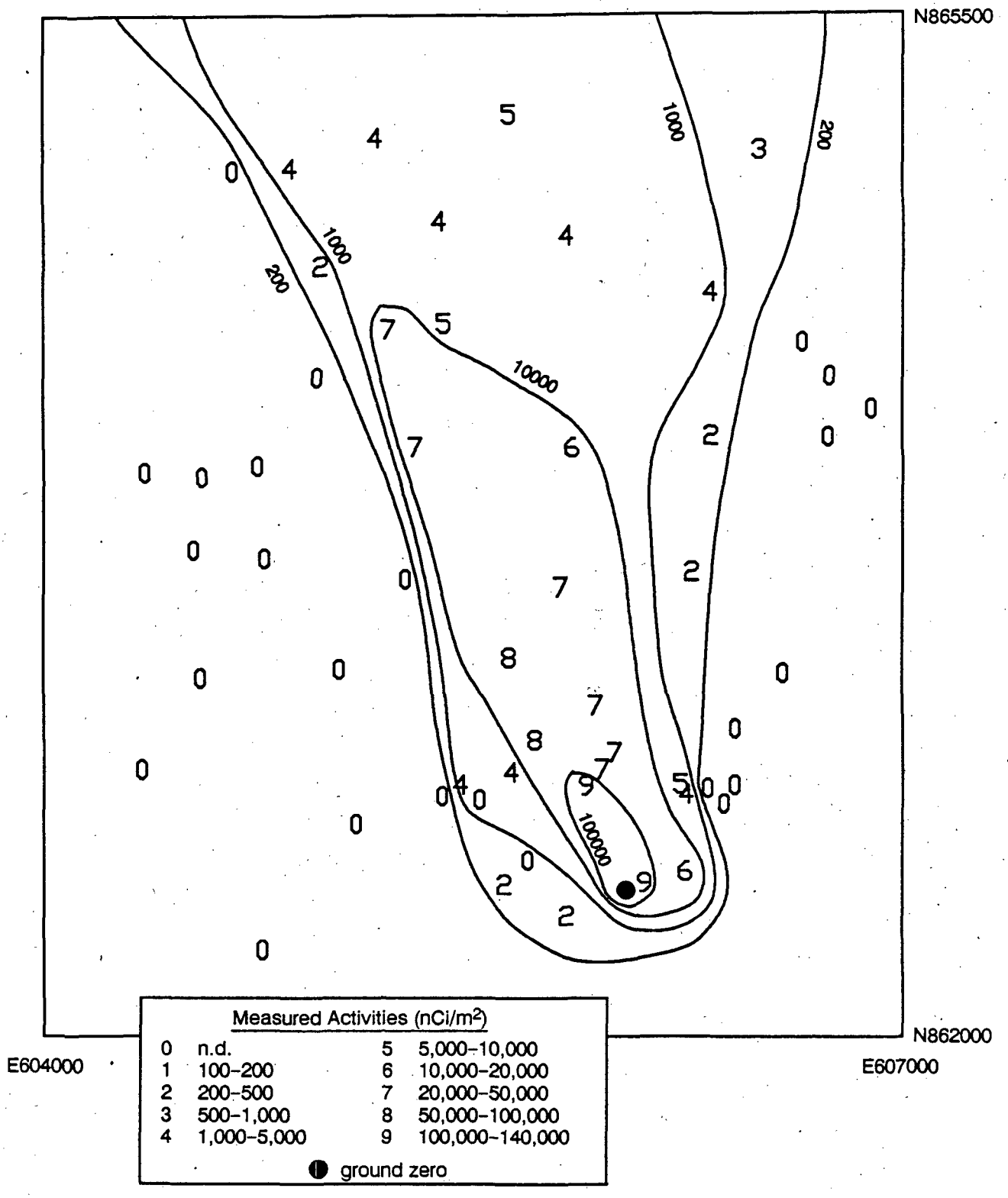

Figure C–2. Activity of ^{241}Am in the Little Feller II area.

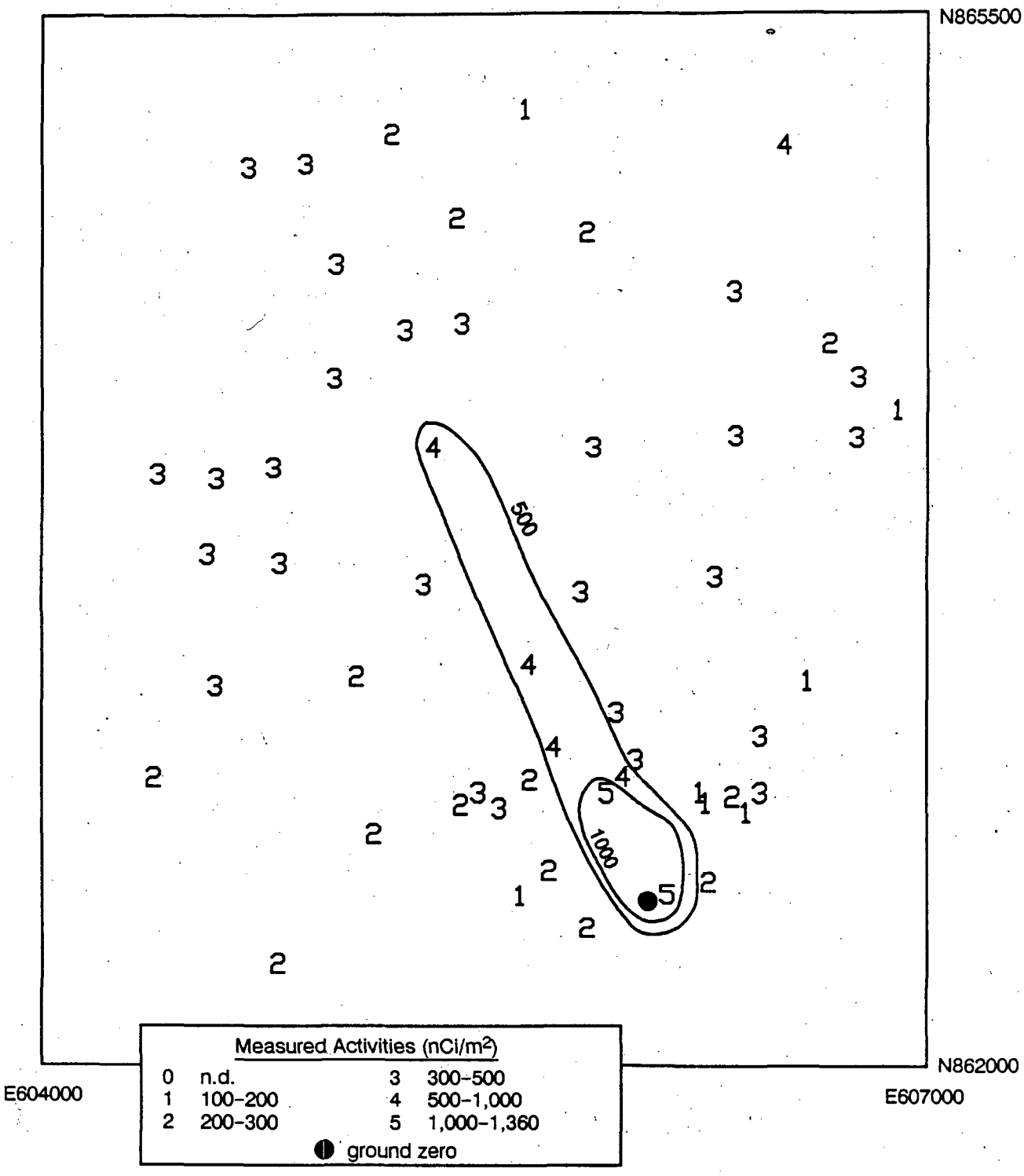

Figure C–3. Activity of ^{137}Cs in the Little Feller II area.